CHEMISTRY OF NEARSHORE SURFICIAL SEDIMENTS FROM SOUTHEASTERN LAKE MICHIGAN

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CHEMISTRY OF NEARSHORE SURFICIAL SEDIMENTS FROM SOUTHEASTERN LAKE MICHIGAN

Abstract. A total of 158 surficial sediment samples were collected from southeastern Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant. These were analyzed for 22 variables: Eh, pH, weight percent insoluble, Ba, Ca, inorganic carbon, organic carbon, total carbon, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Sr, Zn, loss on ignition. Areal distribution maps coupled with correlation coefficients and factor analysis illustrate that carbonates are the dominant component of the sediment and control its chemistry. However, iron and organic compounds are the most chemically active components capable of adsorption, desorption, precipitation, and other trace metal concentration processes. The effect of several small streams discharging to the lake is readily observed using such variables as Ca, organic carbon, and P.

INTRODUCTION

A survey of the surficial sediments in the vicinity of the Donald C. Cook Nuclear Plant located on the southeastern shore of Lake Michigan has been undertaken for the purpose of determining elemental distributions, assessing plant impact on the area, discovering nearby sources of materials that could be mistakenly attributed to the operation of the plant, and gaining an understanding of the possible fate of plant discharges (Fig. 1). A total of 158 stations were occupied in the fall of 1973. These were divided into two classes. First, the inner survey included those stations in the inshore area adjacent to the plant (Rossmann et al. 1974) (Fig. 2). Second, the general survey is comprised of 104 stations collected on a 1.609-km grid (Fig. 3). At the time of collection, subsamples for grain size analysis were obtained. In general, the sediments are sands which progressively become more silty offshore (Seibel et al. 1974).

METHODS

Samples were collected using a Ponar grab sampler. Subsamples for chemical analysis, grain size analysis, and electrode measurements were

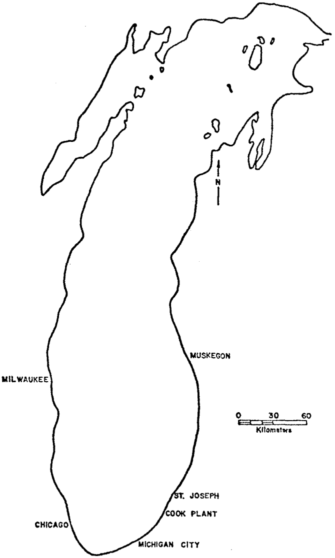

FIG. 1. Location of the Donald C. Cook Nuclear Plant.

removed from the top 2-3 cm of the grab samples. By inserting the electrodes and a thermometer directly into the sediment, field measurements of Eh, pH, and temperature were made on the samples immediately after collection. All pH measurements were made using a rugged pH electrode and a calomel fiber junction saturated potassium chloride reference electrode. Standardization for the measurements was accomplished using commercially available pH buffer solutions. Eh measurements made use of the same reference electrode and a platinum inlay electrode.

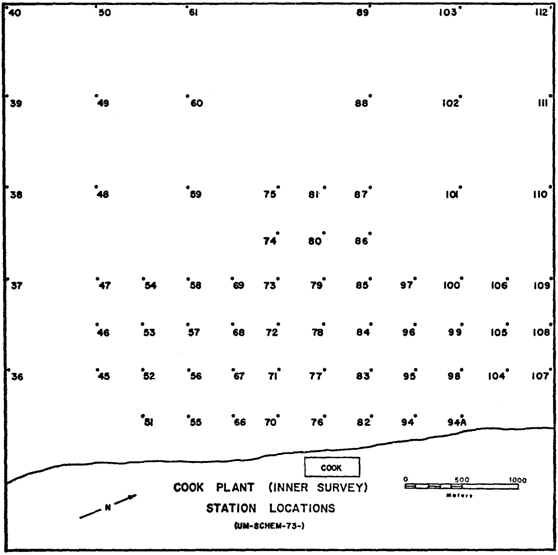

FIG. 2. Inshore survey surficial sediment stations.

Standardization was against Zobell's solution (Zobell 1946). Temperature measurements were made with a standard glass laboratory thermometer. After texture and color were noted, the sediment was stored in polyethylene bags for laboratory analysis.

In the laboratory, the samples were oven dried at 100°C and ground using a mixer mill. Two-gram ground samples for major, minor, and trace element analyses were extracted in a 10% hydrochloric acid-30% hydrogen

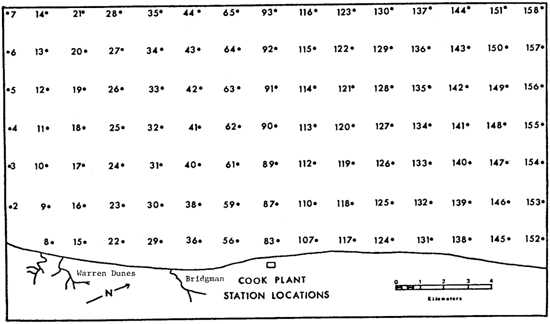

FIG. 3. General survey surficial sediment stations.

peroxide solution kept hot (near boiling) for a period of 40 hr. The extract was separated from the insoluble residue by filtration through fritted glass funnels. The residue was then dried and weighed to obtain weight percent insoluble. The filtered extract was brought to volume in a 50-ml volumetric flask and stored in polyethylene bottles. Analyses for calcium, magnesium, sodium, potassium, manganese, iron, barium, copper, cobalt, nickel, molybdenum, strontium, chromium, and zinc were done by standard atomic absorption spectrophotometry techniques (Perkin Elmer 1968). Phosphorus was done by extraction as molybdenum heteropoly acids and measurement for molybdenum by atomic absorption spectrophotometry (Ramakrishna et al. 1969). Samples for loss on ignition were ignited in a muffle furnace at 1000°C for a period of 1 hr.

Total carbon analyses were done on oven-dried (110°C) ground samples gasometrically by hydroxide absorption using a LECO carbon analyzer. Inorganic carbon was measured using a modification of the LECO carbon analyzer system whereby the sample is reacted with hot 2N hydrochloric acid (Kolpack and Bell 1968). Organic carbon is considered to be equal

to total carbon minus inorganic carbon.

RESULTS

Parameters investigated include isolubles, Eh, pH, barium, calcium, total carbon, inorganic carbon, organic carbon, cobalt, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, nickel, phosphorus, strontium, zinc, and loss on ignition. These parameters were chosen to define major components of the sediment and to describe the distribution of various elements expected to be released by the plant as stable and radioactive species (Appendices A, B). The zinc value for station UM-SCHEM-73-51 is very high. This may be the result of either sample contamination or subsampling problems. Little difference between inner survey and general survey mean elemental concentrations was found to exist (Tables 1, 2). This is expected since the two sets of stations were not chosen to define inshore/offshore relationships. The choice was made solely on the need to most intensively study the sediments nearest the plant.

Each major component of the sediment may have one or more chemical species associated with it. This association can be the result of precipitation, adsorption, and/or chemistry of the parent material. Various components of the sediment which have been described for Lake Michigan are: 1) ferromanganese compounds, 2) clay minerals as contained within the clay sized fraction of the sediment, 3) carbonate minerals, 4) organic matter, and 5) silicates (not including clay minerals) (Callender 1969; Ruch et al. 1970); Schleicher and Kuhn 1970; Shimp et al. 1971; Kennedy et al. 1971; Rossmann 1972).

Each of these components may be defined by one or more chemical parameters, some of which are obvious. Sediments which are relatively enriched with iron and/or manganese contain a relatively high percentage of the ferromanganese component. Organic carbon is self-explanatory. Clay minerals are found associated with clay-size sediment. Thus this fraction of the sediment is defined by the percentage of clay-size material in the sediment. The carbonate sedimentary fraction is well

TABLE 1. General survey mean elemental concentrations. Weight percent; 104 observations.

Variable	Mean	Standard deviation	Minimum	Maximum
Loss on ignition	7.1642	6.0626	.70000	22.390
Insoluble	81.247	14.053	44.490	97.970
Ba	$.36151 \times 10^{-2}$	$.27748 \times 10^{-2}$	$.88200 \times 10^{-3}$	$.12805 \times 10^{-1}$
Ca	3.2217	2.4793	.24510	10.812
Total carbon	2.0100	1.7218	.20000	6.0000
Inorganic carbon	1.6112	1.4942	$.30000 \times 10^{-1}$	5.0100
Organic carbon	.42740	.38579	0.0	2.3700
Co	$.58017 \times 10^{-3}$	$.32829 \times 10^{-3}$	$.14500 \times 10^{-3}$	$.16090 \times 10^{-2}$
Cr	$.16437 \times 10^{-2}$	$.11243 \times 10^{-2}$	$.19000 \times 10^{-4}$	$.54960 \times 10^{-2}$
Cu	$.53411 \times 10^{-3}$	$.52063 \times 10^{-3}$	$.21000 \times 10^{-4}$	$.20060 \times 10^{-2}$
Fe	1.2381	.87439	.12555	5.1520
K	.16194	.12979	$.36999 \times 10^{-1}$	.75423
Mg	1.6572	1.4306	0.0	5.5402
Mn	$.20532 \times 10^{-1}$	$.16752 \times 10^{-1}$	$.73300 \times 10^{-3}$	$.92698 \times 10^{-1}$
Mo	$.30565 \times 10^{-3}$	$.34907 \times 10^{-3}$	$.10000 \times 10^{-5}$	$.16160 \times 10^{-2}$
Na	$.30049 \times 10^{-1}$	$.11955 \times 10^{-1}$	$.10336 \times 10^{-1}$	$.58285 \times 10^{-1}$
Ni	$.10316 \times 10^{-2}$	$.65635 \times 10^{-3}$	$.24200 \times 10^{-3}$	$.26440 \times 10^{-2}$
P	$.22096 \times 10^{-1}$	$.19743 \times 10^{-1}$	$.23840 \times 10^{-2}$	.19299
Sr	$.23581 \times 10^{-2}$	$.11100 \times 10^{-2}$	$.51300 \times 10^{-3}$	$.52960 \times 10^{-2}$
Zn	$.52109 \times 10^{-2}$	$.41359 \times 10^{-2}$	$.11580 \times 10^{-2}$	$.22268 \times 10^{-1}$

TABLE 2. Inner survey mean elemental concentrations. Weight percent; 65 samples.

Variable	Mean	Standard deviation	Minimum	Maximum
Loss on ignition	8.5277	6.4186	.79000	22.390
Insoluble	78.341	14.354	46.170	97.970
Ba	$.43347 \times 10^{-2}$	$.30854 \times 10^{-2}$	$.10240 \times 10^{-2}$	$.12805 \times 10^{-1}$
Ca	3.7013	2.6606	.24510	10.812
Total carbon	2.4097	1.8522	.28000	6.0000
Inorganic carbon	1.9468	1.5953	$.60000 \times 10^{-1}$	4.7800
Organic carbon	.48615	.43151	0.0	2.3700
Co	$.65858 \times 10^{-3}$	$.30483 \times 10^{-3}$	$.14500 \times 10^{-3}$	$.14150 \times 10^{-2}$
Cr	$.17772 \times 10^{-2}$	$.12568 \times 10^{-2}$	$.19000 \times 10^{-4}$	$.54960 \times 10^{-2}$
Cu	$.60783 \times 10^{-3}$	$.54852 \times 10^{-3}$	$.21000 \times 10^{-4}$	$.20060 \times 10^{-2}$
Fe	1.4254	.95421	.12555	5.1520
K	.19406	.13970	$.44439 \times 10^{-1}$	.75423
Mg	1.9462	1.5653	0.0	5.5402
Mn	$.24697 \times 10^{-1}$	$.17732 \times 10^{-1}$	$.10270 \times 10^{-2}$	$.92698 \times 10^{-1}$
Mo	$.40240 \times 10^{-3}$	$.39209 \times 10^{-3}$	$.10000 \times 10^{-5}$	$.16160 \times 10^{-2}$
Na	$.32576 \times 10^{-1}$	$.12901 \times 10^{-1}$	$.11606 \times 10^{-1}$	$.58285 \times 10^{-1}$
Ni	$.11489 \times 10^{-2}$	$.67689 \times 10^{-3}$	$.25900 \times 10^{-3}$	$.25730 \times 10^{-2}$
P	$.25052 \times 10^{-1}$	$.23596 \times 10^{-1}$	$.23840 \times 10^{-2}$	.19299
Sr	$.25835 \times 10^{-2}$	$.11848 \times 10^{-2}$	$.52400 \times 10^{-3}$	$.52960 \times 10^{-2}$
Zn	$.61205 \times 10^{-2}$	$.45836 \times 10^{-2}$	$.11580 \times 10^{-2}$	$.22268 \times 10^{-1}$

defined by high calcium, magnesium, and inorganic carbon concentrations. The silicates (mainly quartz, some feldspar and rock fragments), excluding the clay minerals, are easily defined as sediments with a low loss on ignition, high percentage of coarse-size material, and high weight percent insoluble.

The sediment components of the study area may be divided into two broad categories. These are silicates and non-silicates. The silicates include quartz, feldspars, siliceous rock fragments, and clay minerals. Of these, quartz is by far the most abundant. The clay minerals are not present in amounts which allow any conclusions about their effect to be drawn at this time. The non-silicates include ferromanganese compounds, organic matter, dolostone, and limestone. Of these, the carbonates are most abundant.

SILICATES

The general distribution of sediments relatively rich in this fraction is best represented by a map of weight percent insoluble data. Weight percent insoluble is that fraction of the sediment not dissolved by a near-boiling mixture of 10% v/v hydrochloric acid and 30% hydrogen peroxide for a period of 40 hr.

The distribution of the insoluble fraction of the sediment is shown in Fig. 4. The percentage of insolubles generally decreases in an offshore direction. This is the direct result of dilution of the insolubles by the very fine-grained soluble carbonate and organic matter components. Several disruptions of the general distribution pattern should be noted. The "bull's-eye" of low values to the northwest may not be representative because it is defined by only one point. However, a similar looking low value offshore of Warren Dunes is the result of the addition of relatively high amounts of non-silicates by the two streams entering the lake south of Warren Dunes. Similarly, though not as pronounced, the small area of low percentages offshore of Bridgman is related to the discharge of a stream to the lake.

Offshore of the Cook Plant, an area exists which in enriched in

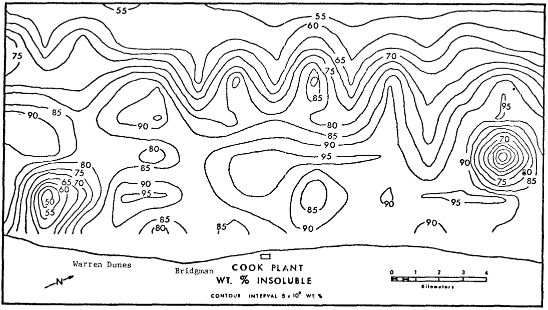

FIG. 4. General survey weight percent insoluble areal distribution.

insolubles. This is possibly the result of construction of the plant and a temporary safe harbor. Because concern was expressed about longshore current depletion of sand due to the safe harbor, sand was transported to the lake south of the plant to insure no erosion of beaches in the area. A general northward direction of the lake's currents further offshore is illustrated by the stringer of sand from the main body leading toward the northeast. In addition, construction of the intakes and discharges of the plant could have allowed a loss of the finer-grained sediments through a winnowing process during dredging. The final distribution feature is the wavy pattern offshore. This is believed to result from a series of ridges and valleys running perpendicular to the shoreline. Those with percentages forming peaks pointing shoreward are valleys and those offshore are ridges, as illustrated by comparing Fig. 4 with a contour map of the area (Fig. 5). The inner survey weight percent insoluble distribution results are quite similar to those for the general survey (Fig. 6). They reflect bottom topography slope (Fig. 7). Samples collected from areas of relatively low slope have a relatively low weight percent insoluble compared to those from areas of high

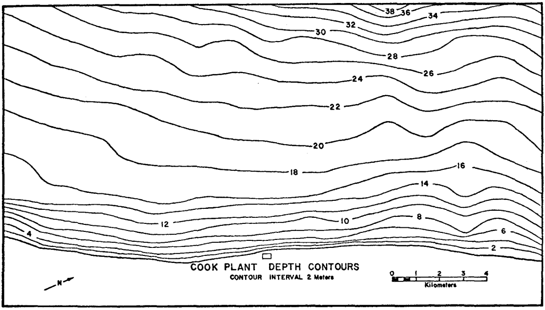

FIG. 5. Bathymetry of general survey study area.

slope. In particular, samples collected from the intervals of 6-8 m, 12-14 m, and 16-18 m are enriched in acid soluble materials. The very low weight percent insoluble south of the plant (68%) may be a non-representative sample enriched with carbonates. However, it does fall on the edge of the 6-8 m zone and may represent a small local bathymetric depression. A decrease in weight percent insoluble in an offshore direction is evident in the general survey but not in the inner survey. This is most likely the result of the inner area occurring in the zone of active current and wave energy dissipation.

For the area surveyed, the sediments are not fine-grained enough to allow a sufficient percentage of clay minerals to be present. Undoubtedly, clay minerals will be an important sedimentary component of the finer-grained sediments further offshore. In order to assess their relative importance, additional samples have been collected from offshore areas. None of the minor or trace elements measured can be associated with the silicate fraction of the sediment with the exception of loss on ignition at 1000°C which will be discussed below.

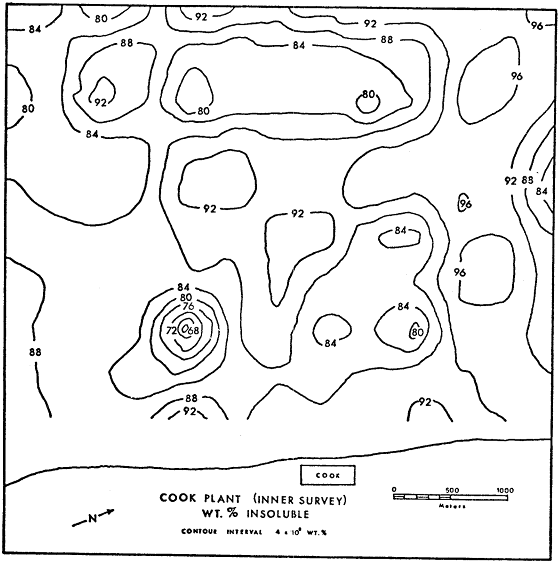

FIG. 6. Inner survey weight percent insoluble areal distribution.

NON-SILICATES

Limestone, dolostone, organic matter, and ferromanganese compounds comprise the non-silicate fraction of the nearshore sediments. As a group, their occurrence is delineated by loss on ignition data (Figs. 8, 9). The distribution pattern obtained from these data indicates this fraction of the sediment is most important offshore and adjacent to streams and in small local depressions or areas of relatively low slope in the inshore regions of the study area.

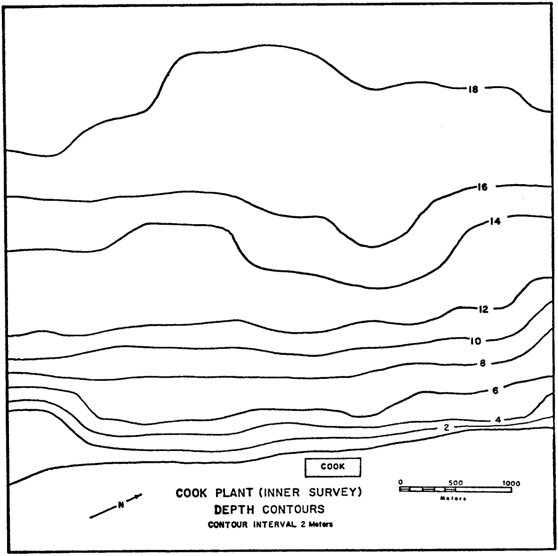

FIG. 7. Bathymetry of inner survey study area.

Carbonates

Since limestone and dolostone are the major constituents of the non-silicate fraction, a pronounced similarity exists between the loss on ignition (Figs. 8, 9) and inorganic carbon (Figs. 10, 11) distribution maps. A notable exception in this comparison is the high loss on ignition towards the northeast. This is not reflected by the inorganic carbon distribution (Figs. 8, 10). Figure 12 illustrates that the anomaly is the result of an organic carbon content higher than that of

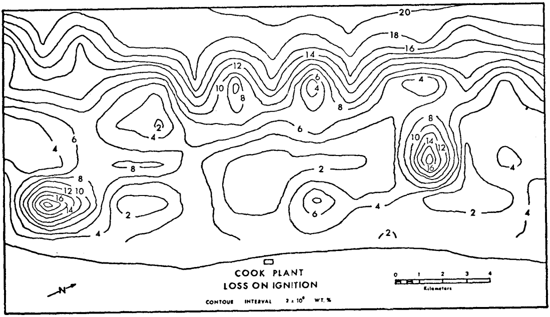

FIG. 8. General survey loss on ignition areal distribution.

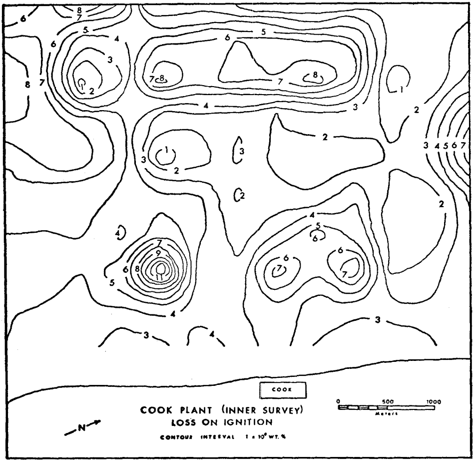

FIG. 9. Inner survey loss on ignition areal distribution.

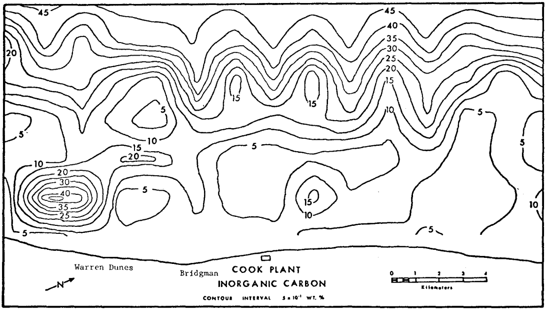

FIG. 10. General survey inorganic carbon areal distribution.

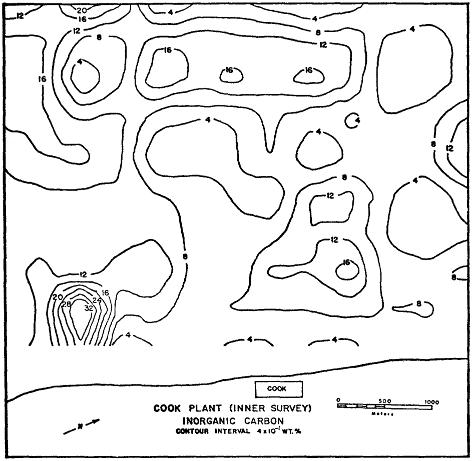

FIG. 11. Inner survey inorganic carbon areal distribution.

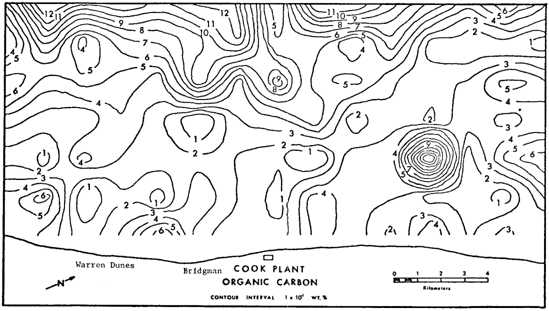

FIG. 12. General survey organic carbon areal distribution.

the survey area in general. For the inner survey, the high loss on ignition does not coincide with the area of high inorganic carbon south of the plant. This is believed in part to represent subsampling problems inherent when dealing with coarse sand and gravel and in part to an increase of organic carbon (Fig. 13) and iron concentrations (see Ferromanganese Section).

Since total carbon (Figs. 14, 15) and inorganic carbon distributions are the same, a discussion of inorganic carbon applies to total carbon. The two patterns are similar because organic carbon is generally present in concentrations lower than those of inorganic carbon (Tables 1, 2). Hence, organic carbon has little effect on the variability of total carbon.

Inorganic carbon is representative of the carbonate component. Numerous features of its distribution confirm that it is transported to the lake as a very fine-grained suspension which eventually settles out in the lower energy offshore environment. South of Warren Dunes, two small streams discharge to the lake (Fig. 10). In the vicinity of these streams outcrops of carbonate-rich clay were observed on the shoreline.

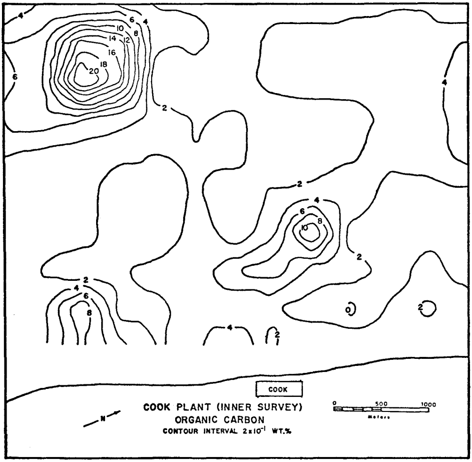

FIG. 13. Inner survey organic carbon areal distribution.

During spring rains and other periods of high water flow, these small streams most likely transport large quantities of detrital carbonates derived from local sources to the lake. This phenomenon is recorded as high inorganic carbon values in the surficial sediments offshore of where these streams discharge into the lake. The fine-grained detrital nature of these shore-derived detrital carbonates is supported by the increase offshore of inorganic carbon, indicating that the carbonates are fine-grained enough to require a relatively quiescent area for deposition. This is further illustrated by its increase in the small valleys perpendicular to shore. Since these are topographic lows, they are less subject to wave and current action.

The final feature of the inorganic carbon distribution is the zone

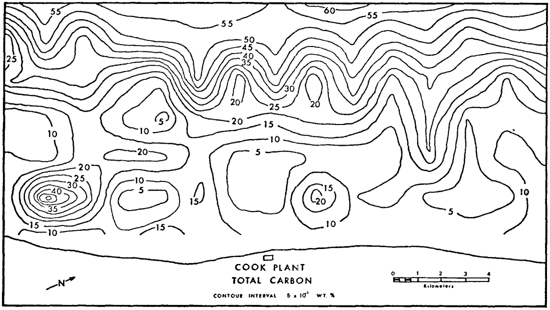

FIG. 14. General survey total carbon areal distribution.

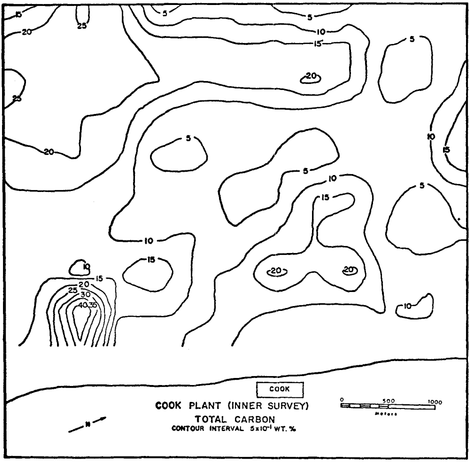

FIG. 15. Inner survey total carbon areal distribution.

of low concentration offshore of the Cook Plant (Fig. 10). This zone exists because construction may have introduced large quantities of carbonate-free sand and/or allowed winnowing out of the finer-grained carbonate materials. The shape of this low concentration zone suggests a current having an average direction of northeastward. In the topographic low (offshore trough) slightly north of the plant, construction has apparently either created this low or winnowed materials such that fine-grained sediments were able to accumulate in an already existing depression (Fig. 11).

In addition to total carbon and inorganic carbon, calcium and magnesium are representative of the limestone ($CaCO_3$) and dolostone ($Ca Mg (CO_3)_2$) subfractions. Calcium percentages in the surficial sediments increase in an offshore direction and are anomalously high offshore of local inputs to the lake (Fig. 16). As expected, its distribution (Figs. 16, 17) is very similar to that of inorganic carbon (Figs. 10, 11). The majority of calcium is transported to the lake as detrital carbonates. Indications of this transport are local high values offshore and south of Warren Dunes and offshore of Bridgman (Fig. 16). The "bull's-eye" to the northeast represents only one point and should be viewed with caution. An area of low calcium offshore of the Cook Plant may be the result of construction activities as discussed previously. Magnesium mimics the distribution of calcium (Figs. 18, 19). This lends support to the notion that the majority of the carbonate present in the study area is dolostone.

Organic Carbon

Other components associated with the non-silicate sediment fraction are organic carbon and iron, which represent the organic carbon and ferromanganese components, respectively. Although it has a distribution somewhat similar to that of total carbon and inorganic carbon, the organic carbon distribution seems to be more energy controlled. Though it increases in an offshore direction (Fig. 12), it does not increase as rapidly as inorganic carbon (Fig. 10). This is based upon its

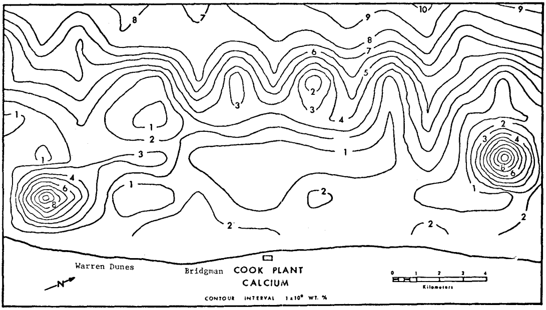

FIG. 16. General survey calcium areal distribution.

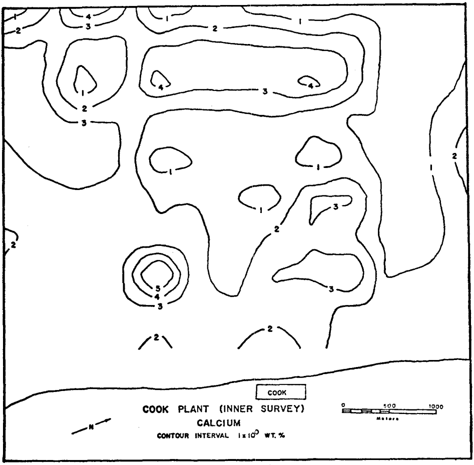

FIG. 17. Inner survey calcium areal distribution.

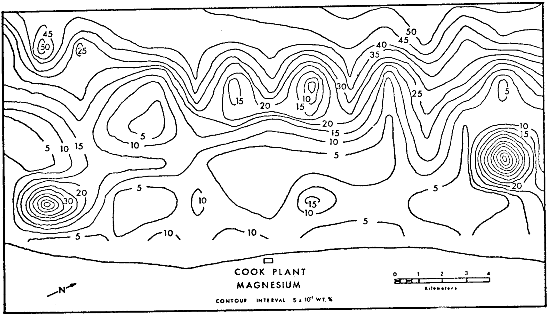

FIG. 18. General survey magnesium areal distribution.

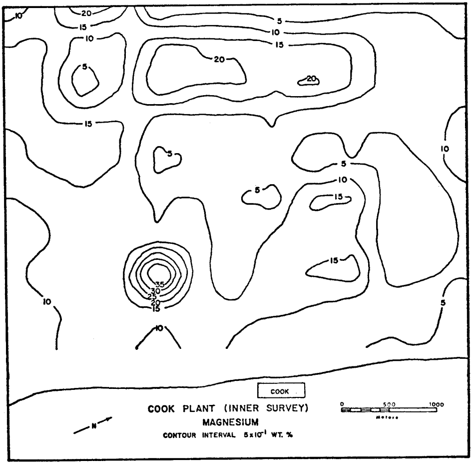

FIG. 19. Inner survey mangesium areal distribution.

inability to reflect topographic changes as well as the inorganic carbon. Plant construction appears to have had an effect upon its distribution in the same manner as it did on the inorganic carbon distribution. The "bull's-eye" high north of the plant is considered to be a non-representa tive sample (Fig. 12). However, this area and the one offshore and south of the plant (Fig. 13) should be viewed as ones which to some degree represent sediments with a high organic carbon component.

Within the inshore region of the study area, organic carbon is high offshore of streams south of Warren Dunes, of a stream receiving discharges from Bridgman's filtration plant, and of an area north of the plant from an unknown source (Fig. 12). These highs are indicative of man's impact on the inshore areas.

Ferromanganese

Since manganese compounds are for the most part absent from the study area, the distribution of iron will be used to describe this sediment component. Having a distribution similar to that of the other nonsilicate variables thus far discussed, iron increases in an offshore direction (Fig. 20). Iron is believed to precipitate in the lake as ferric hydroxide. Because the ferric hydroxide precipitated requires a low energy, low sedimentation rate, and somewhat oxidizing environment of deposition for continued existence, it will be found in the fine-grained offshore sediments. One "bull's-eye" exists offshore of the Cook Plant. Though this is representative of only one data point in the general survey, it is represented by several data points of the inner survey (Fig. 21). This area is the most representative of the ferromanganese sediment component. A high concentration offshore of Bridgman demonstrates that iron is transported to the lake *via* the stream. Another high, adjacent to the shore north of the Cook Plant, is believed to represent an unknown and perhaps intermittent source of drainage to the lake. An area of high iron concentration further offshore from this unknown source may be related to it.

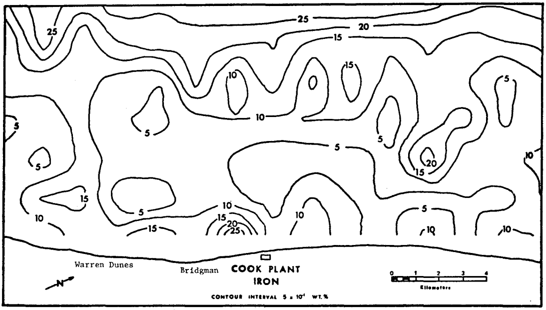

FIG. 20. General survey iron areal distribution.

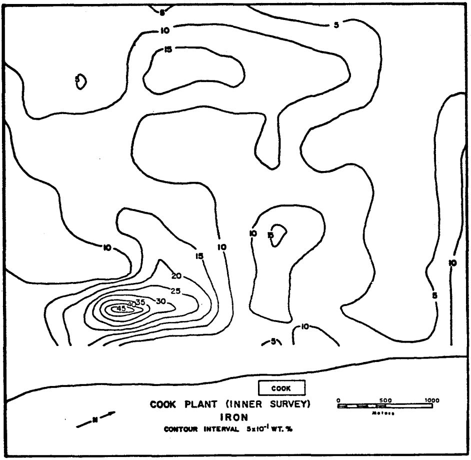

FIG. 21. Inner survey iron areal distribution.

DISCUSSION

The chemical importance of each component may be viewed in two different ways. Each component's importance may be calculated assuming that its importance is in proportion to its abundance or is in proportion to its chemical activity. Abundance calculations have been done assuming that the carbonate component is primarily dolostone, the ferromanganese component is primarily ferric hydroxide, and the silicate component is primarily quartz. The relative abundance of each component is 12%, 2%, and 85% respectively. The organic carbon component averages less than 1%.

Though they are by far the most abundant, the silicates are rather unimportant in adsorption and precipitation processes except for the clay minerals. Since clay minerals are not considered to be abundant within the present bounds of the survey area, they are relatively unimportant. However, they most likely are very important further offshore. Clay minerals will adsorb cations. Illite, kaolinite, chlorite, and vermiculite all exhibit a negative surface charge (Carroll 1959). All these are found in the less than 2-micrometer fraction of sediments in southern Lake Michigan (Shimp et al. 1971). The charge imbalance in illite and chlorite results from a substitution of Al^{3+} for Si^{4+} in the mineral structure (Carroll 1959). In kaolinite, the negative charge results from the negative charges of terminal oxygen atoms at the edges of the structural sheets (Carroll 1959). Since each clay mineral has a negative surface charge, it may be expected to adsorb cations from solution. For this reason, additional samples have been collected from further offshore to assess the relative importance of clay minerals in the scavenging of cations from solution.

In the survey area, the most important components of the sediment with respect to the overall chemistry of the sediment are carbonates and iron compounds. This is illustrated by both correlation (Tables 3, 4) and factor matrices (Tables 5, 6) calculated for samples collected from the survey area. Factor I can be considered representative of the silicates and non-silicates. Since the non-silicates are primarily the

TABLE 3. Correlation matrix for general survey stations. N=104; R @.95=.1927; R @.99=.2515.

Variable	Loss on ignition	Insoluble	Ba	Ca	Total carbon	Inorganic carbon	Organic carbon	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Sr	Zn
Loss on ignition	1.0000																			
Insoluble	-.7895	1.0000																		
Ba	.6825	-.5990	1.0000																	
Ca	.9113	-.8485	.6770	1.0000																
Total carbon	.9703	-.8059	.6900	.9307	1.0000															
Inorganic carbon	.9526	-.8034	.6838	.9297	.9857	1.0000														
Organic carbon	.6807	-.5046	.5047	.5681	.6794	.5537	1.0000													
Co	.8807	-.7571	.6331	.8620	.8846	.8661	.6518	1.0000												
Cr	.8587	-.7205	.6648	.8120	.8921	.8731	.6613	.7941	1.0000											
Cu	.9085	-.7588	.7135	.8618	.9448	.9170	.7336	.8548	.9352	1.0000										
Fe	.8381	-.7090	.6419	.7790	.8437	.8030	.7230	.8059	.8737	.8470	1.0000									
K	.7565	-.6212	.7174	.6954	.7951	.7981	.5865	.8200	.7888	.8520	.6916	1.0000								
Mg	.9049	-.8430	.6509	.9864	.9227	.9205	.5642	.8452	.8099	.8563	.7700	.6728	1.0000							
Mn	.8351	-.6955	.7263	.7967	.8376	.8137	.6351	.7933	.7714	.8074	.8312	.6858	.7915	1.0000						
Mo	.8325	-.7627	.6932	.8758	.8348	.8345	.5267	.7615	.7251	.7877	.7126	.6615	.8761	.7540	1.0000					
Na	.9217	-.8057	.7280	.8900	.9450	.9369	.6316	.8970	.8676	.8950	.8309	.8221	.8772	.8317	.8227	1.0000				
Ni	.9219	-.8027	.6545	.9218	.9394	.9134	.7105	.9244	.8812	.9256	.8678	.7868	.9073	.8372	.7677	.9089	1.0000			
P	.4770	-.4104	.5599	.4558	.4516	.4238	.4247	.5026	.4377	.4333	.5695	.4469	.4228	.7582	.3897	.5210	.5182	1.0000		
Sr	.8232	-.6934	.8000	.7920	.8321	.8061	.6676	.8239	.7902	.8200	.8095	.8208	.7523	.7492	.6607	.8474	.8511	.5861	1.0000	
Zn	.8857	-.7283	.7345	.8362	.9303	.8984	.7252	.8365	.8944	.9602	.8343	.8297	.8340	.8341	.7751	.8829	.9016	.4551	.8098	1.0000

TABLE 4. Correlation matrix for inner survey stations. N=104; R @.95=.1927; R @.99=.2515.

Variable	Loss on ignition	Insoluble	Ba	Ca	Total carbon	Inorganic carbon	Organic carbon	Co	Cr	Cu	Fe	K	Mg	Mn	Mo	Na	Ni	P	Sr	Zn
Loss on ignition	1.0000																			
Insoluble	.7936	1.0000																		
Ba	.7907	-.6488	1.0000																	
Ca	.9028	-.8506	.7641	1.0000																
Total carbon	.6248	-.8339	.5419	.6079	1.0000															
Inorganic carbon	.6965	-.8770	.5924	.6857	.9073	1.0000														
Organic carbon	.0909	-.2046	.0899	.0691	.5114	.1371	1.0000													
Co	.7287	-.8056	.5918	.6957	.6456	.6760	.1501	1.0000												
Cr	.5392	-.6508	.4520	.5847	.4568	.5228	.0521	.5904	1.0000											
Cu	.7500	-.5567	.7167	.6173	.5680	.5567	.2340	.5466	.5303	1.0000										
Fe	.3633	-.6065	.2627	.4423	.3347	.3770	.0394	.5889	.8671	.2165	1.0000									
K	.6598	-.4211	.6069	.4190	.5057	.5116	.1560	.5232	.3069	.8002	.0764	1.0000								
Mg	.8778	-.8311	.6765	.9460	.5528	.6299	.0469	.6635	.5271	.5518	.4165	.3496	1.0000							
Mn	.3270	-.4044	.4622	.3196	.4266	.4555	.1297	.6274	.4094	.3238	.3099	.4047	.1970	1.0000						
Mo	.6023	-.4694	.5233	.6141	.3303	.3959	-.0071	.5868	.2467	.3662	.2136	.3627	.5424	.4222	1.0000					
Na	.7474	-.7623	.5941	.8132	.5352	.6078	.0532	.6076	.5098	.4079	.4361	.3725	.7929	.2673	.4320	1.0000				
Ni	.9135	-.8203	.8079	.8856	.5935	.6361	.1270	.7781	.6355	.7884	.5132	.6230	.8485	.3312	.5650	.7299	1.0000			
P	.7873	-.8484	.6705	.8264	.5813	.6739	.0363	.7539	.8203	.6005	.7589	.4699	.7896	.4329	.4760	.7669	.8520	1.0000		
Sr	.8090	-.8381	.6318	.8763	.5718	.6390	.0889	.6842	.7197	.5999	.6365	.4592	.8116	.2738	.4490	.8400	.8601	.8898	1.0000	
Zn	.3017	-.2810	.3603	.3225	.1869	.1581	.1230	.3647	.0907	.3686	.0625	.3048	.3243	.3223	.3693	.0172	.3456	.2183	.1482	1.000

TABLE 5. Factor matrix for general survey stations.

Variable	Scaled factor loadings						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Loss on ignition	.97436	.14095	$.37252 \times 10^{-1}$	$.65020 \times 10^{-1}$	$.72934 \times 10^{-1}$	$.50451 \times 10^{-1}$	$.16263 \times 10^{-1}$
Insoluble	-.89192	$-.63090 \times 10^{-1}$	$.37481 \times 10^{-1}$	$-.65508 \times 10^{-1}$	-.12901	$.29790 \times 10^{-1}$	$-.31287 \times 10^{-1}$
Ba	.86836	$-.59474 \times 10^{-1}$	.37114	$-.58418 \times 10^{-1}$	$-.56047 \times 10^{-1}$	-.19932	$-.29535 \times 10^{-1}$
Ca	.96752	$.71226 \times 10^{-1}$	$.14627 \times 10^{-1}$	.11498	.17013	$.44383 \times 10^{-1}$	$-.45783 \times 10^{-1}$
Total carbon	.95507	.15679	$-.68041 \times 10^{-1}$	$-.89899 \times 10^{-1}$	$.45512 \times 10^{-1}$	$-.32840 \times 10^{-1}$	$.51907 \times 10^{-1}$
Inorganic carbon	.95239	.14447	$.10762 \times 10^{-1}$	$.70143 \times 10^{-1}$	$.29332 \times 10^{-2}$	$-.28363 \times 10^{-1}$	$.73598 \times 10^{-1}$
Organic carbon	.59296	.12541	-.32382	-.69583	.10945	$-.94833 \times 10^{-1}$	$.14367 \times 10^{-1}$
Co	.92160	$-.26034 \times 10^{-1}$	$.17202 \times 10^{-1}$	$.64280 \times 10^{-1}$	$.14578 \times 10^{-2}$	$.48689 \times 10^{-1}$	$.96719 \times 10^{-2}$
Cr	.84542	$-.86444 \times 10^{-1}$	-.36997	.15892	-.23231	$-.65833 \times 10^{-1}$	$-.16505 \times 10^{-1}$
Cu	.92776	.14124	$-.53840 \times 10^{-1}$	$-.61456 \times 10^{-1}$	-.15410	$.84224 \times 10^{-1}$	$.53013 \times 10^{-1}$
Fe	.74430	-.32592	-.45637	.18599	$-.95826 \times 10^{-1}$	-.11583	-.11369
K	.87031	$.70024 \times 10^{-1}$	.23414	$-.60160 \times 10^{-1}$	-.29464	$-.30828 \times 10^{-1}$	.20258
Mg	.95464	.10948	$-.83300 \times 10^{-2}$	.11860	.16148	$.36378 \times 10^{-1}$	$-.91408 \times 10^{-1}$
Mn	.83746	-.26814	.13329	-.18502	-.10217	$.32885 \times 10^{-1}$	$-.66441 \times 10^{-1}$
Mo	.85039	.15217	.25925	$.37525 \times 10^{-1}$	$.18284 \times 10^{-1}$	-.15115	-.20097
Na	.92765	$.62527 \times 10^{-2}$	$.48928 \times 10^{-1}$	.10377	$.96443 \times 10^{-1}$	$-.69159 \times 10^{-1}$	.10397
Ni	.95226	$.64274 \times 10^{-2}$	-.10233	$.51793 \times 10^{-1}$	$.45219 \times 10^{-1}$	.22357	.11459
P	.53004	-.78414	.17979	-.15856	$.87965 \times 10^{-1}$	$.83671 \times 10^{-1}$	$.18821 \times 10^{-1}$
Sr	.92698	-.16864	$-.39886 \times 10^{-1}$	.10207	.12578	$-.49234 \times 10^{-1}$	$.67036 \times 10^{-1}$
Zn	.84202	.14940	$.71050 \times 10^{-1}$	-.14208	-.15123	.22170	-.23954
% variance	76.5	81.5	85.5	89.0	90.7	91.8	92.9

TABLE 6. Factor matrix for inner survey stations.

Variable	Scaled factor loadings						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Loss on ignition	.97142	.15319	$-.21198 \times 10^{-1}$	$.71690 \times 10^{-1}$	$.80011 \times 10^{-1}$	$.24613 \times 10^{-2}$	$.54910 \times 10^{-1}$
Insoluble	-.93215	$-.63740 \times 10^{-1}$	$-.74198 \times 10^{-1}$	$-.29856 \times 10^{-1}$	-.12802	$.63665 \times 10^{-1}$	$.65047 \times 10^{-1}$
Ba	.83677	$-.70970 \times 10^{-1}$	-.40174	$.85242 \times 10^{-1}$	-.10184	$.86337 \times 10^{-2}$	-.19784
Ca	.96149	$.88601 \times 10^{-1}$	$.87451 \times 10^{-2}$	.12982	.18795	$.59982 \times 10^{-1}$	$.11896 \times 10^{-1}$
Total carbon	.94647	.16580	$.74572 \times 10^{-1}$	-.17876	$.49368 \times 10^{-1}$	-.13899	$-.77936 \times 10^{-1}$
Inorganic carbon	.94687	.15509	$.37488 \times 10^{-1}$	$.34032 \times 10^{-1}$	$-.19257 \times 10^{-1}$	-.14082	$-.31418 \times 10^{-1}$
Organic carbon	.57865	.10020	.10195	-.67021	.10025	$-.56822 \times 10^{-1}$	-.10012
Co	.91919	$-.44834 \times 10^{-1}$	$.25898 \times 10^{-3}$	$.69569 \times 10^{-1}$	$.37726 \times 10^{-1}$	$.18003 \times 10^{-2}$	$-.25452 \times 10^{-1}$
Cr	.82226	-.10992	.42790	$.64107 \times 10^{-1}$	-.25939	$.34356 \times 10^{-1}$	$-.21102 \times 10^{-1}$
Cu	.94534	.15034	$.11244 \times 10^{-1}$	$.89103 \times 10^{-1}$	-.15158	$.25633 \times 10^{-1}$	.10921
Fe	.68707	-.37621	.56766	$.68701 \times 10^{-1}$	-.11877	$.82150 \times 10^{-1}$	-.12511
K	.83335	$.64308 \times 10^{-1}$	.27762	$.69015 \times 10^{-2}$	-.37731	-.15339	.11008
Mg	.94879	.12739	$.44873 \times 10^{-1}$	.11655	.18043	$.89731 \times 10^{-1}$	$.70021 \times 10^{-2}$
Mn	.81488	-.33901	-.18708	-.21162	$-.78982 \times 10^{-1}$	$.55197 \times 10^{-1}$	$-.59619 \times 10^{-2}$
Mo	.84033	.18599	-.24266	.14471	$-.67531 \times 10^{-2}$	.17181	-.20077
Na	.92836	$.19521 \times 10^{-1}$	$-.31369 \times 10^{-1}$	.12368	$.43683 \times 10^{-1}$	-.12979	$.15371 \times 10^{-1}$
Ni	.94304	$-.52653 \times 10^{-3}$	.11028	$.20613 \times 10^{-1}$	.10756	$-.33679 \times 10^{-1}$	.27661
P	.44858	-.82983	-.25763	$-.74093 \times 10^{-1}$	.12599	$-.16792 \times 10^{-2}$	$.58094 \times 10^{-1}$
Sr	.93529	-.18147	$.26171 \times 10^{-1}$	.14540	.10060	$-.75801 \times 10^{-1}$	$.16877 \times 10^{-1}$
Zn	.79889	.15274	$-.96718 \times 10^{-1}$	-.18898	$-.68658 \times 10^{-1}$	.33913	.13085
% variance	74.4	80.4	85.1	88.6	90.7	92.0	93.2

carbonates, the conclusion may be drawn that most of the chemical variability observed for the surficial sediments is related to the carbonates. Areal distributions of each of the trace elements (general survey Figs. 22-32; inner survey Figs. 33-43) illustrate this conclusion. Each distribution is very similar to that of Ca, Mg, and inorganic carbon which are representative of the carbonate distribution.

The manganese distribution is particularly interesting. Manganese is believed to be concentrated in the surficial flocculent material. This makes its distribution particularly subject to local currents. The vast area of low manganese offshore of the plant site indicates a possible disturbance of the floc by pumping and/or construction activities. Later studies are needed to confirm or deny this observation.

In addition, the importance of stream discharges upon the trace element chemistry of the inshore sediments should be noted. The carbonates in the survey area are detrital. This material is partly introduced to the area by several small streams and surface runoff. Referring to Fig. 10, the occurrence of the carbonate-rich clay south of Warren Dunes is reflected in the high carbonate content of the sediment offshore. Since the carbonates are fine grained, they are ultimately deposited in areas of relatively low energy. These areas are found at depths greater than 23 m and local depressions where wave and current energy become sufficiently decreased to allow fine-grained carbonate deposition.

Though the carbonates control the surficial sediment chemistry, they most likely will not be involved in any uptake of materials released from the plant. Only ferromanganese compounds and organic carbon in addition to the clay minerals are expected to be of importance.

Iron and manganese compounds are capable of removing trace elements from solution. This mechanism may be precipitation and/or adsorption. For example, Rossmann (1973) found the occurrence of authigenic psilomelane in ferromanganese nodules from Green Bay, Lake Michigan. This mineral contains barium as well as manganese. Thus barium has been removed from solution through a precipitation process. Likewise, iron may precipitate as iron phosphate in small amounts.

Colloidal hydrated manganese oxides and hydrated iron hydroxides

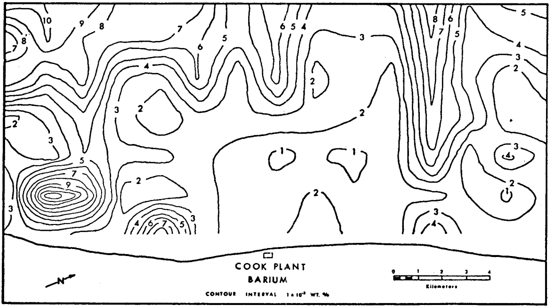

FIG. 22. General survey barium areal distribution.

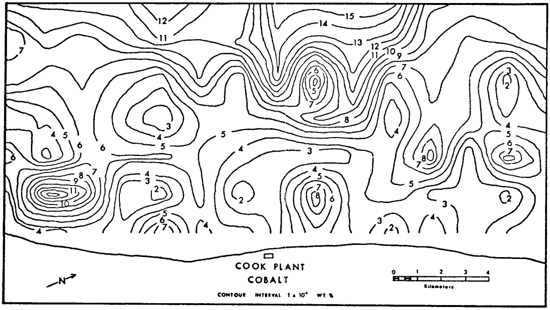

FIG. 23. General survey cobalt areal distribution.

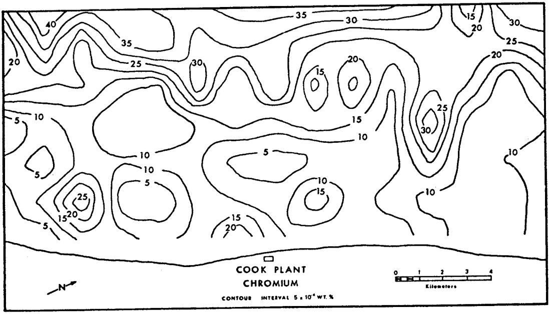

FIG. 24. General survey chromium areal distribution.

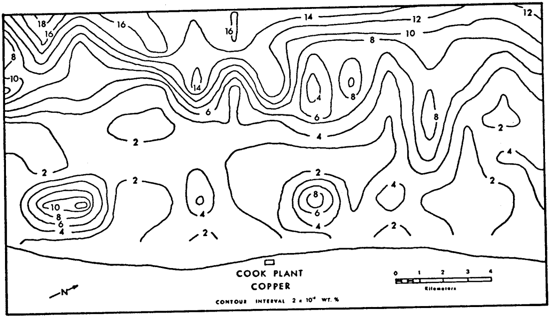

FIG. 25. General survey copper areal distribution.

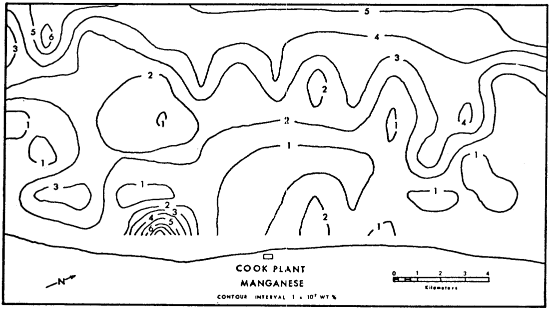

FIG. 26. General survey manganese areal distribution.

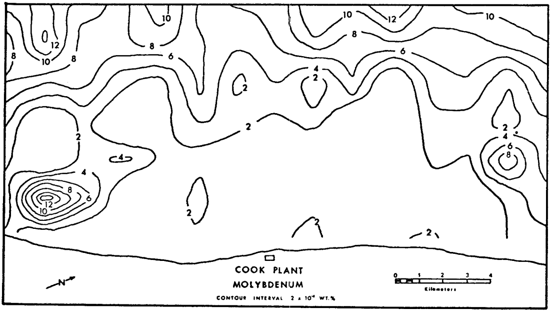

FIG. 27. General survey molybdenum areal distribution.

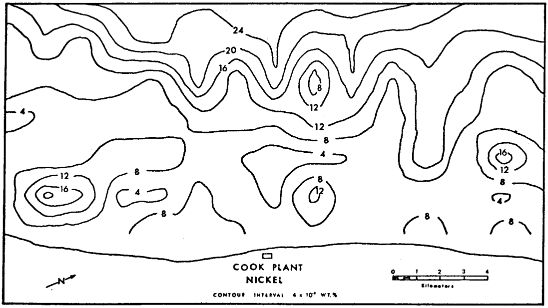

FIG. 28. General survey nickel areal distribution.

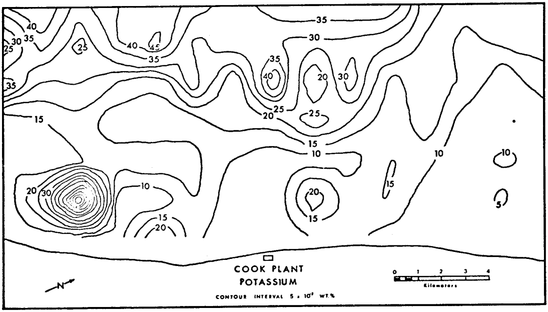

FIG. 29. General survey potassium areal distribution.

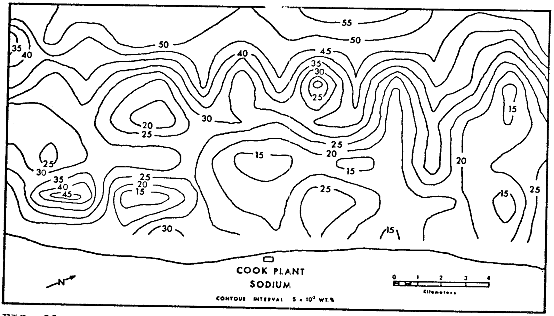

FIG. 30. General survey sodium areal distribution.

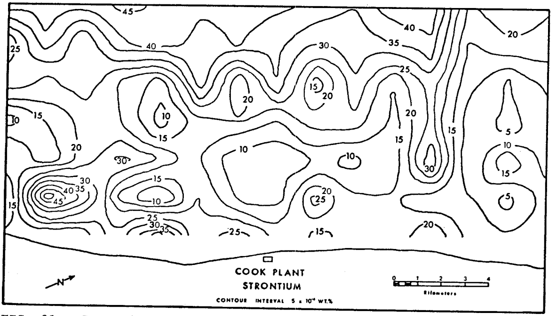

FIG. 31. General survey strontium areal distribution.

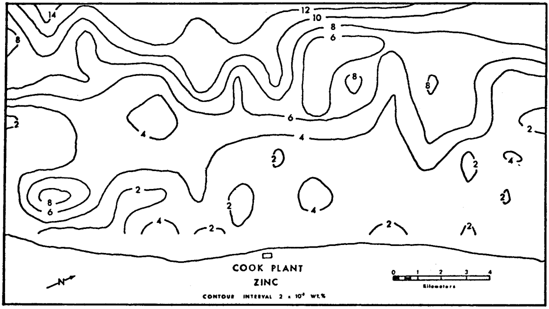

FIG. 32. General survey zinc areal distribution.

adsorb ions from solution. Their ability to adsorb trace ions is related to their surface charge which is determined by the relative amounts of hydroxide and hydrogen surface ions, and thus to pH. The zero point of charge (ZPC), also known as the isoelectric point for solids (IEPS), is the pH at which colloidal hydrated compounds exhibit no net surface charge. Above this pH, the hydrated compounds are negatively charged and below it positively charged. Amorphous iron hydroxide has a ZPC of pH 8.5 (Parks 1965). Since lake water in the vicinity of the Cook Plant has a pH ranging from 8.3 to 8.8, the ferric hydroxide sols can be expected to exhibit no net surface charge. However, within the sediments the iron hydroxides would carry a positive charge since the pH of the sediments is seldom above 8.0.

On the other hand, hydrated manganese oxides in Lake Michigan may be expected to have a strong negative surface charge. Healy, Herring and Fuerstenau (1966) report a ZPC of pH 1.8 for the synthetic compound 10°A-manganite. Since one of the predominant manganese minerals in Green Bay is todorokite, the naturally occurring equivalent of 10°A-manganite, manganese oxides in the lake will exhibit a net negative surface charge

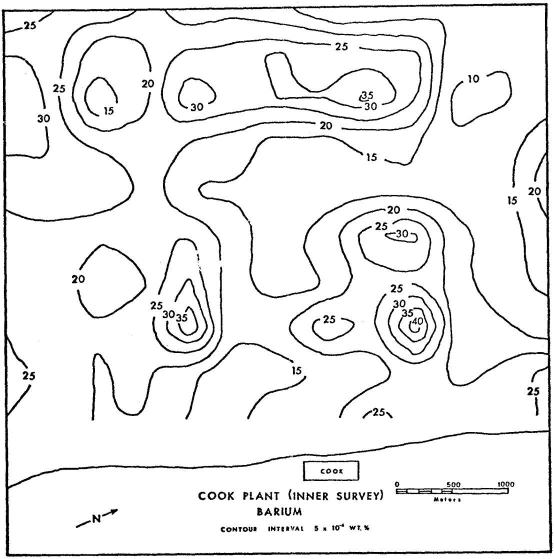

FIG. 33. Inner survey barium areal distribution.

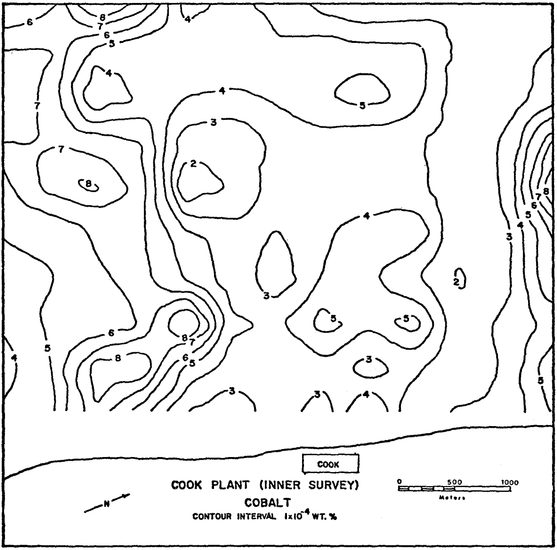

FIG. 34. Inner survey cobalt areal distribution.

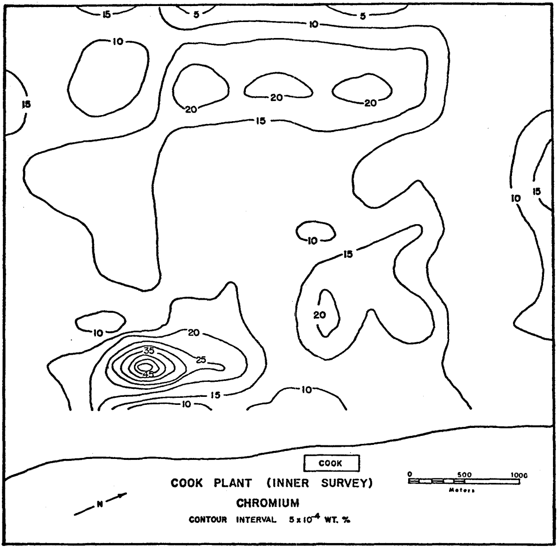

FIG. 35. Inner survey chromium areal distribution.

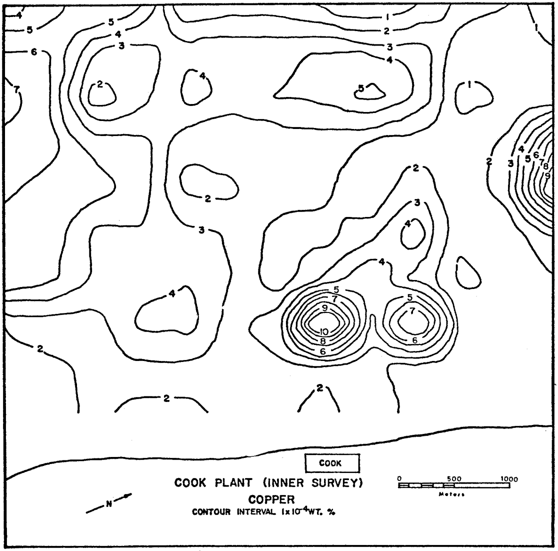

FIG. 36. Inner survey copper areal distribution.

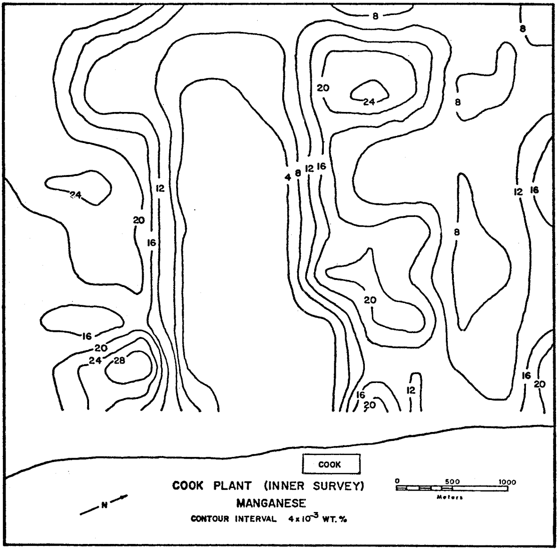

FIG. 37. Inner survey manganese areal distribution.

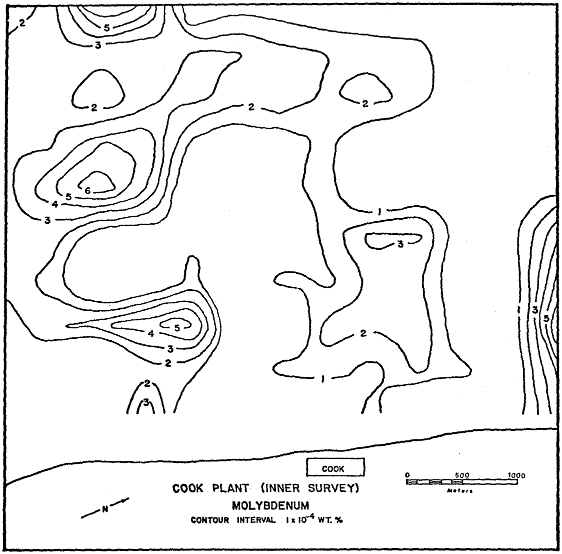

FIG. 38. Inner survey molybdenum areal distribution.

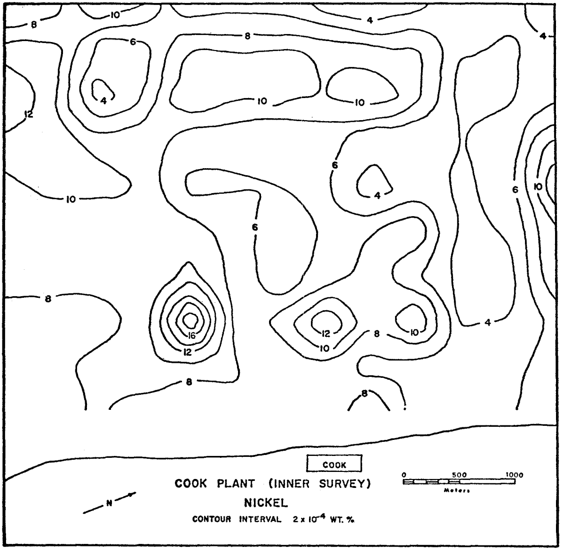

FIG. 39. Inner survey nickel areal distribution.

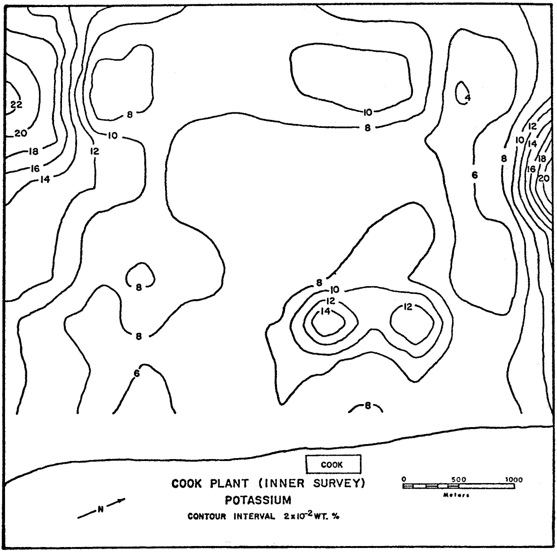

FIG. 40. Inner survey potassium areal distribution.

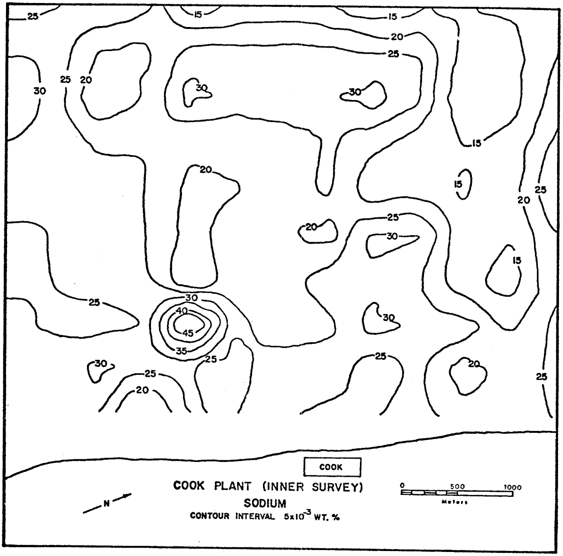

FIG. 41. Inner survey sodium areal distribution.

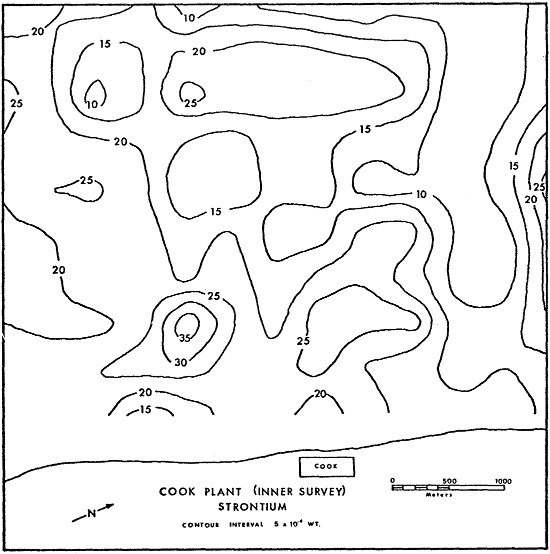

FIG. 42. Inner survey strontium areal distribution.

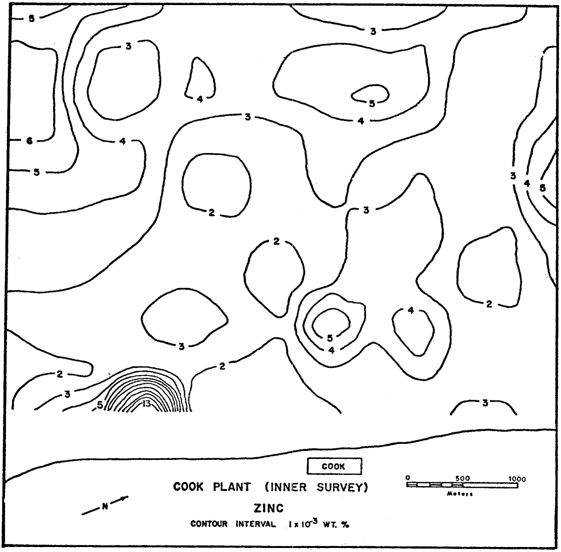

FIG. 43. Inner survey survey zinc areal distribution.

(Rossmann et al. 1972). Therefore hydrated manganese oxides will adsorb cations, and hydrated ferric hydroxide may or may not adsorb anions. Rossmann (1973) illustrated for Green Bay where the pH of the water averages below 8.0 that anions are associated with iron compounds and cations with manganese compounds in ferromanganese nodules.

Although cations undoubtedly are associated with the manganese compounds, this is not evident from the factor matrices (Tables 5, 6). Because manganese compounds are so much less abundant than the other major components of the sediment, their effect on surficial sediment chemistry is impossible to assess. Samples from further offshore may aid in assessing the relative role of manganese compounds.

The role of the iron compounds is illustrated by Factors II and III (Tables 5, 6). The only elements associated to any degree with the Fe are Cr, P, organic carbon and perhaps Mn. This is predicted if adsorption is occurring. Chromium (chromate) and phosphorus (phosphate) exist as anions in solution. Iron and phosphorus may be precipitated as an iron phosphate. The only difference between the two surveys is that Fe and organic carbon are not associated for the inner survey stations.

The distribution of phosphorus in the surficial sediment (Fig. 44) is particularly interesting. An area of very high concentration is directly offshore of Bridgman, which has a filtration treatment plant located near the mouth of the stream discharging to the lake. The phosphorus in the sediments is definitely linked to this creek. Measurement of orthophosphate and total phosphate have yielded values as high as 1430 ppb P and 3225 ppb P, respectively. This is compared to maxima of 21.9 ppb P and 92.0 ppb P, respectively, for other streams discharging into the survey area. The predominant longshore current is northward, as illustrated by the area of relatively high phosphorus projecting toward the north and extending nearly as far as the Cook Plant. The relatively high phosphorus within 1500 m of the plant may be derived from the Bridgman filtration plant or may represent several small bathymetric depressions near the Cook Plant (Fig. 45).

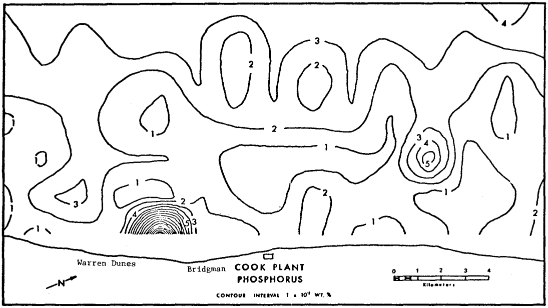

FIG. 44. General survey phosphorous areal distribution.

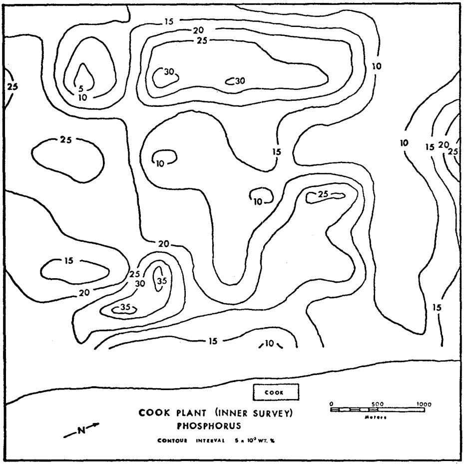

FIG. 45. Inner survey phosphorous areal distribution.

Organic matter consists of a combination of organic detritus transported to the lake by streams or runoff and dead organisms indigenous to the lake. Factors III and IV (Tables 5, 6) illustrate this component. Factor II shows that organic carbon has a direct relationship with iron and chromium, perhaps through the occurrence of both in the fine-grained flocculent material at the surface of the sediment. However, Factor III shows that it is not related either directly or inversely to any of the other components. Organic matter may become an important component of the sediment for accumulation of those trace metals utilized and concentrated by organisms which die and become incorporated into the lake's sediment.

CONCLUSIONS

The distributions of insoluble, loss on ignition, barium, calcium, total carbon, inorganic carbon, organic carbon, cobalt, chromium, copper, iron, potassium, magnesium, manganese, molybdenum, sodium, nickel, total phosphorus, strontium, and zinc in the surficial sediments in southeastern Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant have led to numerous conclusions. These include:

1) Three small streams discharging into Lake Michigan south of the plant have profoundly increased surficial sediment concentrations of most of the chemical parameters measured.

2) Construction of the plant's intakes and discharges may have altered the surficial sediment chemistry offshore of the plant.

3) The St. Joseph River has no observable effect upon the lake sediments adjacent to the plant for those parameters investigated.

4) The stream which discharges just south of the plant is capable of delivering various chemical species to waters offshore of the plant.

5) The predominant current several miles offshore is northeastward.

6) An unknown source of substances measured exists north of the plant.

7) Carbonates control surficial sediment elemental concentrations in the survey area.

8) All variables factor with the carbonates.

9) Weight percent insoluble is inversely related to most variables.

10) Phosphorus, manganese and iron are associated with the ferromanganese component.

11) Chromium is associated with iron compounds.

12) Organic carbon is associated with iron compounds to a small degree but for the most part is independent of all measured parameters.

These conclusions should supplant those made by Rossmann et al. (1974).

Although clay minerals may be important, they, like the manganese compounds, are present in quantities so small that conclusions about their importance are impossible to make at this time. Because of the need to assess the role of clay minerals and manganese compounds, additional samples will be collected from areas further offshore. Finally, to establish the true area influenced by the St. Joseph River, additional samples to the north of the plant will be collected.

Any monitoring of the sediments for the impact of plant discharges should be done in areas of high iron, manganese, organic carbon, or clay mineral content where accumulation and concentration of radioactive isotopes to be released to the lake by the plant directly and indirectly are most likely. Since elements are relatively high in areas of low slope or in depressions, this monitoring should concentrate on those areas bounded by the 6-8 m, 12-14 m, and 16-22 m contour intervals, the small offshore trending trough slightly north of the plant, and the offshore extreme of the general survey.

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APPENDIX A. Results of general survey analyses. Weight percent; 0.0 = undetectable (Appendix C).

Station no. UM-SCHEM-73	Insoluble	Loss on ignition	Calcium	Magnesium	Iron	Manganese ($x10^{-3}$)	Sodium ($x10^{-2}$)	Potassium ($x10^{-2}$)	Barium ($x10^{-3}$)	Cobalt ($x10^{-4}$)	Chromium ($x10^{-3}$)	Copper ($x10^{-4}$)
2	95.49	2.15	0.631	0.203	0.668	13.5	2.19	9.22	1.68	3.77	0.311	1.12
3	87.84	4.82	2.21	0.822	0.669	15.5	3.46	16.8	3.79	6.85	0.826	2.97
4	95.64	1.90	0.556	0.0395	0.396	5.69	2.39	9.50	1.63	2.96	0.070	1.02
5	74.98	10.8	3.95	2.25	1.47	36.0	4.72	40.8	10.2	8.74	2.51	12.8
6	81.95	7.25	3.13	1.62	0.949	20.9	3.07	22.7	5.98	5.77	1.38	5.52
7	55.89	19.5	8.03	3.95	2.01	45.3	5.63	39.7	11.1	9.94	2.98	12.9
8	61.10	1.92	1.21	0.149	0.606	11.2	1.88	12.2	3.35	3.37	0.077	1.12
9	46.17	22.4	10.8	5.51	1.64	37.7	4.53	28.9	12.8	14.2	1.30	11.3
10	95.60	1.73	0.701	0.140	0.408	6.40	2.32	10.4	2.12	2.72	0.282	1.05
11	90.26	4.19	1.62	0.737	0.789	13.7	2.94	14.9	3.43	4.55	0.914	2.00
12	74.77	10.7	4.28	2.30	1.15	27.6	3.24	23.6	6.42	6.32	1.92	6.95
13	59.60	18.6	7.49	5.54	2.88	68.4	5.32	37.7	10.4	8.78	3.78	15.2
14	55.13	19.5	8.24	4.11	2.85	53.6	4.80	45.7	9.95	10.6	4.79	20.1
15	91.10	2.91	1.54	0.404	1.30	18.6	2.05	9.76	2.80	4.48	1.21	1.14
16	69.52	12.5	5.02	2.41	1.74	36.7	4.60	75.4	10.1	11.0	3.12	12.2
17	83.54	6.40	2.78	1.41	1.14	21.4	2.94	14.9	4.98	6.35	1.22	2.91
18	82.85	7.01	3.11	1.91	1.14	25.1	3.29	17.8	5.80	6.76	1.12	3.07
19	72.11	11.7	5.15	2.80	1.14	29.8	4.11	26.2	8.90	7.20	2.17	7.87
20	73.52	11.6	4.78	2.47	1.08	25.2	4.30	24.9	8.00	7.45	1.66	6.07
21	55.86	18.9	7.55	4.53	2.24	50.9	5.83	33.3	10.0	11.2	3.63	14.5
22	89.55	4.03	1.62	0.552	1.48	19.1	2.23	9.25	2.65	3.43	1.26	0.79
23	96.31	1.30	0.450	0.083	0.256	6.83	1.31	7.01	1.52	2.35	0.211	0.42
24	80.36	8.46	3.39	1.96	0.943	22.0	3.63	18.1	3.52	6.11	1.05	3.45
25	91.70	3.97	1.21	0.603	0.568	11.9	2.09	11.9	2.40	4.16	0.537	1.48
26	83.91	7.18	2.62	1.50	0.883	21.1	2.86	19.6	3.15	5.55	1.16	4.28
27	58.97	17.6	7.89	3.76	2.20	31.7	5.38	40.5	7.13	9.41	3.41	12.8
28	54.34	20.4	8.24	4.58	2.79	50.2	4.90	39.9	6.89	10.6	4.10	18.6
29	78.66	6.66	3.93	1.41	2.19	92.7	3.66	27.7	9.65	8.68	1.02	4.39
30	97.97	1.15	0.245	0.00	0.126	4.71	1.35	7.24	1.02	1.90	0.0	0.21
31	79.67	8.65	3.77	1.84	0.983	25.4	3.93	20.7	3.72	6.45	1.38	3.91
32	95.78	1.99	0.542	0.187	0.358	99.0	1.64	10.8	1.13	2.18	0.539	1.42
33	90.02	4.14	1.47	0.680	0.516	17.1	2.41	15.8	2.31	4.82	0.950	2.97
34	57.03	19.0	7.65	4.22	2.34	46.2	5.17	46.3	5.88	11.1	4.09	17.6
35	55.69	19.3	7.94	4.40	2.53	45.9	5.56	34.5	5.78	13.5	3.45	15.4

APPENDIX A cont.

Station no. UM-SCHEM-73	Molybdenum ($x10^{-4}$)	Nickel ($x10^{-4}$)	Total phosphorus ($x10^{-2}$)	Strontium ($x10^{-3}$)	Zinc ($x10^{-3}$)	Total carbon	Inorganic carbon	Organic carbon	Eh, mv	pH	Depth, m
2	0.0	5.58	0.769	1.02	1.83	0.69	0.23	0.46	419	8.51	14.0
3	0.0	8.51	1.65	2.26	4.54	1.20	1.04	0.16	417	8.05	15.9
4	4.13	2.59	0.799	0.868	1.60	0.52	0.16	0.36	445	7.79	17.4
5	8.64	13.7	2.97	3.16	10.9	3.06	2.28	0.78	60	7.75	19.8
6	6.58	8.34	2.25	2.15	6.66	1.83	1.59	0.24	397	7.70	22.0
7	11.2	16.6	3.47	4.42	11.4	5.41	4.74	0.67	125	7.55	24.7
8	0.0	6.15	0.909	1.68	1.88	0.59	0.21	0.38	444	7.85	5.5
9	16.2	20.3	3.15	5.30	10.2	5.25	4.61	0.64	---	----	15.9
10	0.0	4.10	0.928	1.07	2.13	0.70	0.61	0.09	454	7.47	16.2
11	0.0	4.66	1.61	1.61	3.49	0.96	0.69	0.27	466	7.67	18.3
12	6.83	8.95	2.55	2.50	7.37	2.96	2.52	0.44	91	7.51	21.0
13	14.6	15.6	3.65	3.94	12.4	5.23	4.36	0.87	66	7.51	23.2
14	12.6	19.2	3.99	4.29	15.6	5.96	4.56	1.40	78	7.36	25.6
15	0.0	4.88	1.72	1.84	1.62	0.87	0.72	0.15	461	7.79	7.9
16	8.24	17.3	3.46	4.04	7.43	3.33	4.39	0.0	478	7.66	15.9
17	0.0	7.32	2.63	2.24	4.49	1.77	1.33	0.44	457	7.55	16.5
18	0.0	6.13	2.53	2.24	4.38	1.83	1.59	0.24	125	7.49	18.9
19	7.42	11.5	2.82	2.86	8.34	3.43	2.87	0.56	434	7.16	21.3
20	6.69	9.79	2.44	2.52	6.87	3.21	2.84	0.37	19	7.43	24.1
21	9.14	24.6	3.76	4.27	12.2	5.55	4.46	1.09	110	7.30	27.2
22	0.0	6.68	2.04	2.98	1.79	1.11	0.78	0.33	384	7.74	8.2
23	0.0	3.27	0.624	1.47	1.54	0.35	0.15	0.20	447	7.45	15.9
24	4.56	12.0	2.21	3.13	5.97	2.29	2.00	0.29	421	7.32	18.0
25	0.0	5.72	1.26	2.00	4.20	1.04	0.65	0.39	432	7.47	18.3
26	0.0	9.92	1.92	1.97	5.83	1.88	1.42	0.46	88	7.45	22.8
27	7.76	23.2	3.62	4.20	11.6	4.87	4.18	0.69	38	7.37	25.0
28	7.50	25.2	3.81	4.64	13.9	5.95	4.73	1.22	96	7.34	28.7
29	0.0	15.8	19.3	4.49	6.40	1.67	0.90	0.77	---	----	11.0
30	0.0	2.66	0.0	0.524	1.42	0.28	0.21	0.07	480	7.54	18.0
31	0.0	12.0	2.19	2.58	5.38	2.29	2.01	0.28	170	7.49	18.3
32	0.0	4.80	0.739	0.771	2.96	0.44	0.21	0.23	435	7.65	20.1
33	0.0	7.45	1.23	1.32	4.58	1.08	0.70	0.38	386	7.40	22.6
34	8.98	25.6	3.85	4.39	13.4	5.12	4.39	0.73	49	7.26	24.7
35	11.8	24.3	3.71	4.41	12.0	5.68	4.63	1.05	116	7.33	29.0

APPENDIX A cont.

Station no. UM-SCHEM-73	Insoluble	Loss on ignition	Calcium	Magnesium	Iron	Manganese ($x10^{-3}$)	Sodium ($x10^{-2}$)	Potassium ($x10^{-2}$)	Barium ($x10^{-3}$)	Cobalt ($x10^{-4}$)	Chromium ($x10^{-3}$)	Copper ($x10^{-4}$)
36	88.94	4.03	1.98	0.805	1.04	17.2	2.57	10.6	2.62	3.64	1.06	1.22
40	88.96	4.64	0.414	0.808	0.744	20.2	2.27	16.5	2.21	5.05	1.07	3.80
41	81.21	8.26	3.40	1.89	0.861	21.9	2.99	13.3	2.65	5.26	1.06	3.31
42	59.43	18.2	7.56	4.11	2.26	44.5	4.89	33.7	6.44	9.28	3.61	15.8
43	57.86	18.8	8.02	4.33	2.30	42.5	4.88	28.4	6.09	9.83	2.79	12.4
44	55.38	19.6	6.40	4.46	2.84	52.3	5.35	38.1	7.68	11.8	3.36	14.8
56	82.49	4.60	2.54	1.35	3.28	3.07	2.58	6.75	1.61	4.87	2.81	2.96
59	95.23	0.82	0.739	0.393	0.603	1.03	1.90	5.80	1.53	1.45	0.988	1.73
61	97.02	1.09	0.343	0.011	0.448	11.7	1.32	9.68	1.65	3.83	0.321	1.23
62	79.40	9.20	3.71	2.08	1.10	23.2	3.08	17.8	2.69	5.90	1.83	4.43
63	87.68	5.82	2.18	1.11	0.675	20.0	2.30	14.9	1.93	5.07	1.05	3.06
64	61.43	17.0	6.99	3.89	2.19	42.8	4.47	35.4	4.58	11.2	3.09	16.2
65	53.83	20.8	8.61	4.74	3.10	51.2	5.01	31.3	4.27	9.50	3.78	16.0
83	89.26	3.49	2.27	0.973	0.635	13.4	2.14	6.81	1.71	2.76	1.11	2.22
87	96.60	1.32	0.518	0.170	0.293	8.07	1.67	5.66	1.23	3.04	0.707	1.03
89	97.85	0.95	0.273	0.0	0.156	5.78	1.37	7.10	0.882	2.37	0.285	0.28
90	85.76	5.45	2.41	1.28	0.834	20.8	2.59	17.1	3.00	6.26	1.20	3.66
91	63.01	16.5	7.04	3.58	1.93	42.6	4.67	46.4	7.08	14.1	3.57	17.1
92	56.97	19.2	8.06	4.29	2.01	41.3	4.98	30.4	6.18	14.6	2.88	11.8
93	51.96	21.3	8.61	4.70	3.02	50.8	5.21	38.0	7.47	16.1	3.83	15.8
107	92.59	3.88	1.04	0.218	1.54	26.8	2.56	10.7	2.81	5.79	0.700	1.10
110	80.44	8.52	2.54	1.69	1.09	21.8	3.15	24.8	2.35	9.11	1.98	10.6
112	97.18	1.50	0.385	0.193	0.287	4.82	1.72	9.54	1.12	2.30	0.570	0.32
113	79.75	8.26	3.84	2.01	1.08	23.8	3.70	29.0	2.91	9.32	1.84	6.79
114	93.03	2.29	1.19	0.395	0.472	14.4	1.98	13.5	1.52	3.93	0.968	2.60
115	69.76	16.5	7.55	4.12	1.41	36.5	4.80	28.4	2.67	12.6	2.11	7.23
116	51.90	21.3	9.34	4.97	3.32	52.8	5.92	39.9	3.79	15.4	3.76	15.9
117	93.45	2.62	1.25	0.378	0.616	11.0	1.91	11.3	1.77	4.19	0.664	3.63
118	91.92	4.37	1.54	0.697	0.489	9.56	2.62	11.8	1.18	3.56	0.746	1.50
119	96.48	1.66	0.488	0.173	0.285	7.07	1.34	8.57	0.799	3.06	0.524	1.06
120	77.59	4.79	4.32	2.31	1.08	27.1	3.86	20.3	2.11	8.92	1.64	5.08
121	64.86	15.4	6.02	3.94	1.92	39.4	4.46	32.6	2.97	12.4	2.78	10.5
122	56.88	19.3	8.85	4.73	1.28	37.4	4.87	29.3	2.98	13.3	1.69	7.41
123	51.76	21.5	9.48	5.20	3.30	54.5	6.10	38.1	4.06	16.3	3.82	16.4

APPENDIX A cont.

Station no. UM-SCHEM-73	Molybdenum ($x10^{-4}$)	Nickel ($x10^{-4}$)	Total phosphorus ($x10^{-2}$)	Strontium ($x10^{-3}$)	Zinc ($x10^{-3}$)	Total carbon	Inorganic carbon	Organic carbon	Eh, mv	pH	Depth, m
36	0.0	7.14	2.29	2.12	1.64	1.00	0.76	0.24	413	7.96	9.1
40	1.36	5.70	1.30	1.57	4.64	1.20	0.95	0.25	109	7.64	18.6
41	4.50	9.73	1.82	1.95	5.16	1.97	2.03	0.0	200	7.42	20.7
42	6.99	23.4	3.26	4.00	13.7	5.35	4.27	1.08	44	7.39	24.1
43	6.39	21.2	3.15	3.81	10.8	5.38	4.52	0.86	108	7.38	26.5
44	5.37	24.6	3.50	4.14	12.7	5.83	4.58	1.25	76	7.31	30.2
56	1.48	9.55	3.13	2.90	2.19	1.15	1.02	0.13	421	7.92	8.5
59	0.0	5.76	0.942	1.02	1.57	0.31	0.10	0.21	443	7.60	16.4
61	0.0	4.17	0.699	0.699	2.96	0.33	0.13	0.20	436	7.70	18.9
62	0.0	11.3	2.40	2.16	5.96	2.28	1.96	0.32	142	7.58	21.3
63	0.0	8.19	1.43	1.56	5.50	1.60	1.20	0.40	428	7.66	23.5
64	4.50	23.4	1.34	4.05	12.6	4.98	3.75	1.23	120	7.41	25.9
65	6.18	25.7	3.69	4.19	14.0	6.00	4.78	1.22	61	7.14	32.0
83	0.0	5.46	1.44	1.99	2.17	0.96	0.83	0.13	383	7.81	8.2
87	0.0	3.19	0.574	0.795	2.51	0.20	0.13	0.07	150	7.76	16.8
89	0.0	2.42	0.544	0.513	1.92	0.27	0.14	0.13	410	7.42	19.2
90	0.0	9.64	2.75	1.56	5.65	1.72	1.37	0.35	343	7.67	21.6
91	4.48	23.8	3.46	3.68	11.2	4.63	3.67	0.96	53	7.52	24.1
92	6.17	24.5	3.27	3.58	10.2	5.25	4.73	0.52	134	7.05	28.3
93	6.33	26.4	3.75	4.17	12.9	5.41	5.01	0.40	51	7.13	33.8
107	4.38	7.07	2.41	1.40	2.23	0.78	0.35	0.43	---	----	6.7
110	0.87	13.9	2.84	2.77	6.07	2.31	1.80	0.51	87	7.66	16.2
112	0.0	2.99	0.535	1.06	2.42	0.58	0.58	0.0	439	7.67	19.5
113	2.95	15.5	2.49	2.47	6.41	2.49	1.86	0.63	62	7.56	21.3
114	0.83	5.72	1.11	1.32	3.84	1.48	1.03	0.45	424	7.51	24.4
115	9.55	18.4	2.95	3.12	5.31	4.33	3.77	0.56	180	7.32	27.7
116	13.0	26.1	3.86	3.79	13.1	6.21	4.96	1.25	48	7.43	35.4
117	0.0	5.94	1.00	1.62	2.43		0.45	0.37	---	----	8.2
118	0.0	5.33	1.24	1.64	2.48	1.00	0.69	0.31	334	7.50	14.9
119	0.0	4.24	0.651	0.965	2.56	0.52	0.11	0.41	395	7.30	19.2
120	0.0	12.7	2.79	2.30	5.81	2.47	2.33	0.14	77	7.49	21.3
121	6.29	20.4	3.30	2.94		4.20	3.63	0.57	56	7.49	24.4
122	6.85	19.9	3.12	3.25	4.50	5.04	4.74	0.30	118	7.26	28.3
123	10.4	27.1	3.72	3.52	12.9	6.29	4.99	1.30	115	7.16	36.0

APPENDIX A cont.

Station no. UM-SCHEM-73	Insoluble	Loss on ignition	Calcium	Magnesium	Iron	Manganese ($x10^{-3}$)	Sodium ($x10^{-2}$)	Potassium ($x10^{-2}$)	Barium ($x10^{-3}$)	Cobalt ($x10^{-4}$)	Chromium ($x10^{-3}$)	Copper ($x10^{-4}$)
124	93.96	1.84	1.20	0.390	0.319	8.86	1.35	8.10	1.13	1.58	0.715	0.87
125	89.73	4.64	1.82	0.781	0.509	13.9	1.87	15.4	1.64	5.11	1.37	5.83
126	94.68	2.53	0.720	0.347	0.704	12.0	1.66	15.5	1.52	4.87	0.733	1.50
127	94.24	3.94	0.903	0.498	0.294	8.38	1.69	10.5	1.11	3.18	0.790	1.88
128	90.63	5.02	1.60	0.892	0.629	17.0	2.02	13.8	1.53	5.13	1.10	2.93
129	64.41	16.7	7.64	4.09	1.29	37.6	4.83	26.8	2.81	12.6	2.01	7.25
130	52.22	21.4	9.61	5.10	3.08	53.9	5.71	40.3	4.19	16.1	3.57	15.5
131	87.37	3.60	2.95	0.739	1.26	25.6	2.24	5.80	5.37	5.09	1.30	3.25
132	96.35	1.50	0.596	0.227	0.331	5.75	1.94	6.37	1.95	2.98	0.820	1.34
133	82.67	20.7	2.97	1.74	2.44	41.2	3.56	11.8	6.37	9.48	2.29	6.67
134	76.70	10.2	4.80	2.51	1.29	26.0	3.26	19.3	6.80	6.83	3.66	9.78
135	72.07	2.09	6.00	3.24	1.32	34.0	4.10	17.1	7.46	7.43	2.34	7.67
136	58.37	18.3	9.16	5.29	1.62	42.4	4.72	18.8	8.10	8.13	2.25	9.20
137	53.12	20.8	10.3	5.56	2.69	53.0	5.04	22.7	9.08	9.39	3.32	13.8
138	93.53	3.33	1.54	0.473	0.287	9.23	2.07	7.34	2.44	2.37	0.688	1.38
139	95.43	1.59	0.721	0.385	0.522	11.8	2.05	5.52	2.10	2.78	0.866	1.31
140	96.17	1.49	0.592	0.392	0.568	5.69	1.68	4.07	1.03	2.15	0.581	1.15
141	93.21	2.97	0.675	0.508	1.80	46.1	1.83	7.62	4.66	6.67	0.784	2.29
142	76.41	10.3	4.56	2.85	1.15	36.4	3.52	14.8	3.34	6.31	2.24	6.85
143	70.16	12.9	5.42	3.34	1.31	46.0	3.68	13.4	3.50	6.86	2.33	7.33
144	53.88	20.4	8.68	5.02	2.16	50.1	4.60	16.8	4.09	8.88	1.15	12.8
145	88.90	4.18	2.25	0.815	1.14	23.5	1.89	6.55	2.92	4.32	0.852	2.57
146	96.34	1.41	0.585	0.388	0.367	5.34	1.16	4.89	0.859	1.84	0.424	1.19
147	45.31	5.01	11.6	7.17	0.900	16.2	2.39	11.8	4.38	8.81	1.09	5.15
148	95.25	2.93	0.782	0.539	0.445	10.9	1.54	5.93	1.10	3.13	0.537	1.62
149	94.74	3.07	0.652	0.477	0.371	12.3	1.26	6.42	1.13	1.93	0.540	2.30
150	64.15	15.9	7.12	4.35	1.52	49.7	3.13	16.2	3.98	7.82	2.47	7.80
151	53.83	20.7	9.15	5.28	2.02	51.6	4.86	20.0	5.25	8.49	3.48	11.7
152	-----	3.92	2.10	1.15	0.977	16.9	3.20	6.89	1.87	4.83	1.22	1.91
153	84.18	6.51	3.08	1.68	1.02	22.0	3.15	10.6	2.66	5.08	1.71	5.70
154	91.73	2.55	1.06	0.763	1.14	16.9	2.53	7.21	2.44	4.96	1.27	3.46
155	92.50	2.97	1.15	0.726	0.781	12.0	2.33	6.74	1.40	3.73	0.976	2.66
156	78.69	9.24	4.19	2.35	0.956	25.6	3.38	12.6	2.92	6.43	1.81	6.10
157	61.76	16.5	7.74	4.35	1.62	50.3	5.00	18.0	4.71	8.65	2.89	10.3
158	54.36	19.9	9.54	5.09	2.27	59.2	5.00	20.1	5.22	9.38	3.47	13.0

APPENDIX A cont.

Station no. UM-SCHEM-73	Molybdenum ($x10^{-4}$)	Nickel ($x10^{-4}$)	Total phosphorus ($x10^{-2}$)	Strontium ($x10^{-3}$)	Zinc ($x10^{-3}$)	Total carbon	Inorganic carbon	Organic carbon	Eh, mv	pH	Depth, m
124	0.0	5.90	0.629	1.48	1.54	0.53	0.35	0.18	430	8.04	4.9
125	0.0	8.00	1.68	1.64	3.94	1.28	0.94	0.34	217	7.49	13.7
126	0.0	6.05	1.01	1.18	2.85	0.67	0.34	0.33	160	7.45	18.3
127	0.0	4.92	0.932	1.32	3.12	1.08	0.79	0.29	118	7.51	20.1
128	0.0	7.89	1.35	1.58	4.52	1.79	1.48	0.31	328	7.51	23.5
129	8.25	18.1	2.96	3.47	6.64	3.93	3.23	0.70	121	7.55	31.1
130	15.2	25.6	3.70	4.42	12.9	5.89	4.95	0.94	73	7.22	40.2
131	2.93	12.4	1.49	2.90	2.83	1.10	0.59	0.51	---	----	5.5
132	0.0	4.13	0.652	1.11	2.17	0.40	0.22	0.18	428	7.94	11.9
133	2.71	16.9	6.03	3.59	5.26	2.46	0.89	1.57	---	----	18.3
134	3.62	15.1	2.68	2.70	7.56	2.73	2.54	0.19	99	7.47	21.9
135	5.11	15.1	2.86	2.79	8.35	3.08	2.84	0.24	109	7.67	25.6
136	7.33	18.2	3.41	3.89	6.48	4.76	4.59	0.17	108	7.43	29.3
137	8.86	23.1	3.46	4.31	10.8	5.78	5.05	0.73	114	7.60	36.6
138	0.0	4.16	0.697	1.39	1.86	0.60	0.41	0.19	442	7.81	7.0
139	0.0	4.68	0.810	1.25	2.45	0.35	0.21	0.14	416	8.06	14.6
140	1.77	4.95	0.585	0.477	1.50	0.31	0.18	0.13	412	7.82	16.4
141	3.51	8.96	1.50	0.718	7.33	0.52	0.11	0.41	---	----	20.1
142	6.00	13.1	2.64	1.19	6.81	2.60	2.27	0.33	110	7.63	25.6
143	7.16	14.6	2.76	1.44	6.95	3.22	3.10	0.12	129	7.72	27.4
144	10.9	19.8	3.52	1.94	10.4	5.43	4.99	0.44	- 68	7.20	36.6
145	2.20	10.9	1.72	1.24	2.72	1.16	0.80	0.36	---	----	4.9
146	2.07	3.77	0.603	0.383	1.97	0.29	0.21	0.08	478	7.90	12.8
147	10.5	18.8	1.40	2.04	4.41	1.38	0.81	0.57	135	7.56	18.3
148	0.0	4.70	0.793	0.421	2.29	0.92	0.66	0.26	373	7.76	20.1
149	2.19	4.23	0.866	0.485	2.68	0.94	0.37	0.57	352	7.54	23.8
150	8.99	15.4	3.47	1.89	8.68	4.00	3.88	0.12	140	7.67	27.4
151	10.7	20.1	4.94	2.38	9.37	5.65	4.92	0.73	90	7.37	34.7
152	3.31	6.82	2.24	1.22	1.82	0.98	0.84	0.14	77	7.51	35.0
153	6.29	8.17	2.47	1.28	3.99	1.77	1.33	0.44	86	7.74	29.6
154	2.50	9.01	1.58	0.889	3.49	0.90	0.18	0.72	188	7.94	25.9
155	4.13	4.30	1.48	0.629	1.39	0.79	0.43	0.36	435	7.90	21.3
156	6.56	10.5	2.46	1.08	3.95	2.46	2.01	0.45	---	----	19.8
157	10.1	16.6	3.41	1.87	9.02	4.09	4.00	0.09	410	7.90	16.2
158	11.7	20.8	3.52	2.05	9.55	5.26	4.80	0.46	411	7.92	9.1

APPENDIX B. Results of inner survey analyses. Weight percent; 0.0 = undetectable (Appendix C).

Station no. UM-SCHEM-73	Insoluble	Loss on ignition	Calcium	Magnesium	Iron	Manganese ($x10^{-3}$)	Sodium ($x10^{-2}$)	Potassium ($x10^{-2}$)	Barium ($x10^{-3}$)	Cobalt ($x10^{-4}$)	Chromium ($x10^{-3}$)	Copper ($x10^{-4}$)
36	88.9	4.03	1.98	0.805	1.04	17.2	2.57	10.6	2.62	3.64	1.06	1.22
37	88.8	5.10	1.95	0.802	0.784	17.2	2.46	14.4	2.32	4.64	1.13	6.32
39	78.0	9.55	4.15	1.88	1.05	24.3	3.33	23.6	3.55	7.77	1.60	7.62
40	89.0	4.64	0.414	0.808	0.744	20.2	2.27	16.5	2.21	5.05	1.07	3.80
45	85.8	3.84	2.48	1.13	2.51	26.9	3.14	7.72	1.96	8.66	2.09	2.39
46	87.7	4.02	2.51	1.26	0.534	13.3	2.35	6.94	2.07	5.00	0.948	2.67
47	85.0	5.31	2.73	1.38	1.10	22.8	2.68	8.36	1.85	5.87	1.50	3.85
48	80.4	7.82	3.89	1.89	1.38	25.8	2.64	12.0	2.84	8.13	1.90	5.57
49	94.7	0.79	0.581	0.260	0.481	8.68	1.60	5.78	1.22	3.21	0.555	1.51
50	76.8	9.94	5.10	2.47	1.06	26.4	3.15	12.4	2.97	9.46	1.78	6.87
51	87.3	2.28	2.33	1.31	1.02	19.8	1.16	4.44	2.00	5.54	0.459	1.61
52	80.6	4.17	2.72	1.20	5.15	36.4	2.84	6.03	2.13	9.21	5.50	2.98
53	85.5	5.88	2.99	1.39	0.503	18.2	2.53	9.23	2.16	6.20	1.04	4.25
54	86.4	3.93	2.42	1.12	1.55	21.1	2.72	7.79	2.00	6.34	1.74	3.61
55	96.9	2.78	1.69	0.594	0.532	11.4	2.53	6.95	1.52	3.14	0.949	1.74
56	82.5	4.60	2.54	1.35	3.28	3.07	2.58	6.75	1.61	4.87	2.81	2.96
57	63.8	13.4	7.20	4.71	2.21	3.90	5.68	7.04	4.01	9.80	1.95	4.54
58	87.7	5.68	2.07	1.02	1.59	2.65	1.66	9.58	3.10	4.94	1.16	4.03
59	95.2	0.82	0.739	0.393	0.603	1.03	1.90	5.80	1.53	1.45	0.988	1.73
60	77.2	8.33	4.33	2.66	1.93	2.98	3.19	10.1	3.30	4.27	2.45	4.40
61	97.0	1.09	0.343	0.0113	0.448	11.7	1.32	9.87	1.65	3.83	0.321	1.23
66	87.3	4.69	2.69	1.36	0.597	1.30	2.48	7.29	1.30	2.39	1.06	2.39
67	86.7	3.50	2.07	1.00	2.80	2.63	2.29	6.99	1.23	3.64	2.44	2.43
68	87.1	3.23	2.31	1.18	1.79	1.93	2.70	7.36	1.71	4.29	1.61	2.59
69	87.4	4.55	2.39	1.29	1.37	2.05	2.28	7.68	1.60	3.55	1.52	3.04
70	89.6	3.61	2.12	0.923	0.668	1.08	2.75	7.99	2.17	3.65	0.878	2.43
71	87.7	3.94	2.46	1.21	0.883	1.45	2.85	8.22	1.27	3.07	1.24	2.72
72	91.6	3.52	1.51	0.705	0.768	0.957	2.24	8.35	1.77	3.76	1.13	3.90
73	93.2	2.48	1.30	0.602	0.667	0.733	2.17	5.83	1.39	2.50	1.04	1.51
74	93.6	1.99	1.04	0.550	0.721	1.14	2.12	5.79	1.33	3.02	1.04	1.70
75	90.7	3.24	1.66	1.01	0.907	1.22	2.16	6.78	1.29	3.69	1.02	2.66
76	----	4.57	1.34	0.439	0.480	0.785	2.32	7.61	1.72	2.48	0.656	1.46
77	87.0	4.69	2.56	1.17	1.33	1.85	3.02	8.05	1.67	3.72	1.41	2.46

APPENDIX B cont.

Station no. UM-SCHEM-73	Molybdenum ($x10^{-4}$)	Nickel ($x10^{-4}$)	Total phosphorus ($x10^{-2}$)	Strontium ($x10^{-3}$)	Zinc ($x10^{-3}$)	Total carbon	Inorganic carbon	Organic carbon	Eh, mv	pH	Depth, m
36	0.0	7.14	2.29	2.12	1.64	1.00	0.76	0.24	413	7.96	9.1
37	2.44	8.59	1.81	1.77	3.81	1.45	1.03	0.42	35	7.50	13.7
39	2.48	13.5	2.74	2.70	7.41	2.62	2.08	0.54	75	7.58	18.9
40	1.36	5.70	1.30	1.57	4.64	1.20	0.95	0.25	109	7.64	18.6
45	0.0	8.48	2.63	2.52	2.04	5.35	4.27	1.08	349	7.77	8.5
46	3.88	7.32	1.22	1.92	2.56	0.87	0.95	0.0	381	7.66	13.1
47	0.0	8.83	2.29	2.38	2.97	1.39	1.00	0.39	208	7.51	13.7
48	6.93	10.9	2.79	2.58	4.82	2.02	1.74	0.28	122	7.69	17.1
49	0.0	3.40	0.0	0.837	1.89	2.45	0.08	2.37	391	7.62	18.6
50	7.82	12.3	2.36	2.50	5.57	2.67	2.37	0.30	97	7.54	18.9
51	3.85	6.90	1.26	1.22	22.3	0.57	0.06	0.51	---	----	7.0
52	0.0	9.87	3.80	2.93	2.67	1.21	1.08	0.13	432	7.81	8.2
53	4.85	8.94	1.69	2.14	3.09	1.57	1.39	0.18	362	7.40	12.2
54	0.0	8.54	2.38	2.19	2.79	0.89	1.04	0.0	429	7.63	13.4
55	0.0	5.33	1.10	1.66	1.16	0.67	0.48	0.19	338	7.81	6.7
56	1.48	9.55	3.13	2.90	2.19	1.15	1.02	0.13	421	7.92	8.5
57	5.49	20.4	3.90	4.06	4.18	2.00	1.65	0.35	---	----	12.5
58	1.46	10.7	1.66	1.96	2.66	0.99	1.14	0.0	363	7.67	13.4
59	0.0	5.76	0.942	1.02	1.57	0.31	0.10	0.21	443	7.60	16.4
60	4.56	12.6	3.40	2.75	4.27	2.07	2.04	0.03	382	7.70	17.7
61	0.0	4.17	0.699	0.699	2.96	0.33	0.13	0.20	436	7.70	18.9
66	0.0	7.76	1.41	2.31	1.88	1.18	0.84	0.34	402	7.73	6.1
67	0.0	8.21	2.23	2.21	1.91	0.88	0.48	0.40	399	7.85	8.5
68	0.0	7.50	1.92	2.61	2.73	0.95	0.67	0.28	369	7.81	11.9
69	0.0	7.20	1.85	2.34	2.16	1.02	0.67	0.35	380	7.64	13.7
70	0.0	6.90	1.38	2.38	1.38	0.99	0.31	0.68	419	7.93	5.8
71	1.57	6.99	2.11	2.39	1.59	1.13	0.89	0.24	378	7.60	8.8
72	0.0	8.29	1.21	1.84	2.21	1.05	0.42	0.63	---	----	12.8
73	1.60	4.83	1.21	1.62	1.30	0.58	0.53	0.05	408	7.78	14.0
74	0.0	5.09	1.16	1.35	2.14	0.30	0.38	0.0	378	7.64	15.5
75	0.71	6.14	1.53	1.64	2.59	0.70	0.37	0.33	189	7.76	17.1
76	0.0	5.44	0.902	1.58	1.62	0.58	0.40	0.18	412	7.97	5.8
77	1.58	7.90	2.20	2.72	3.11	1.04	0.82	0.22	336	7.79	9.1

APPENDIX B cont.

Station no. UM-SCHEM-73	Insoluble	Loss on ignition	Calcium	Magnesium	Iron	Manganese ($x10^{-3}$)	Sodium ($x10^{-2}$)	Potassium ($x10^{-2}$)	Barium ($x10^{-3}$)	Cobalt ($x10^{-4}$)	Chromium ($x10^{-3}$)	Copper ($x10^{-4}$)
78	82.8	7.58	3.14	1.46	1.24	2.29	2.36	17.6	2.98	5.44	2.31	13.4
79	87.3	4.07	2.20	1.13	1.69	21.3	2.84	8.05	1.52	4.14	1.94	3.27
80	95.3	2.28	0.665	0.356	0.819	15.5	1.86	5.26	1.63	3.75	0.935	1.66
81	89.8	1.86	1.75	0.966	1.13	18.2	2.65	7.16	1.38	3.49	1.54	2.32
82	88.2	3.11	2.29	0.736	1.56	26.4	2.49	8.58	2.82	5.65	1.38	3.34
83	89.2	3.49	2.27	0.973	0.635	13.4	2.14	6.81	1.71	2.76	1.11	2.22
84	84.7	5.22	3.18	1.51	0.751	19.6	3.25	10.2	2.36	4.45	1.40	3.83
85	85.1	6.39	2.92	1.35	1.17	21.6	2.78	10.2	2.34	4.27	1.91	5.13
86	84.01	2.14	3.17	1.62	0.947	19.2	3.26	8.66	2.91	4.87	1.40	2.88
86B	77.9	9.71	4.41	1.94	1.45	25.6	3.06	21.0	4.72	6.34	3.15	16.0
87	96.6	1.32	0.518	0.170	0.293	8.07	1.67	5.66	1.23	3.04	0.707	1.03
88	79.1	8.50	4.30	2.12	1.36	26.6	3.23	12.2	3.58	5.56	2.30	5.50
89	97.8	0.95	0.273	0.0	0.156	5.78	1.37	7.10	0.882	2.37	2.85	0.28
94	93.0	2.04	1.56	0.549	0.858	11.9	2.72	6.51	2.03	2.14	1.37	1.24
94A	91.8	2.79	1.55	0.438	0.603	13.1	2.30	6.72	2.28	3.30	1.04	1.57
95	91.4	3.58	1.84	0.739	0.455	12.0	2.72	8.88	2.31	3.41	1.08	1.62
96	79.6	8.27	4.34	1.88	1.07	24.0	2.85	16.0	4.46	5.39	2.30	9.59
97	88.4	4.81	2.29	1.12	0.715	15.1	2.54	7.74	2.49	3.15	1.17	2.74
98	91.8	3.22	1.81	0.781	0.277	12.2	1.75	6.19	1.91	1.95	0.930	1.31
99	95.2	1.98	0.952	0.422	0.193	7.94	2.88	6.79	1.69	2.31	0.519	1.51
100	96.8	1.11	0.560	0.249	0.141	6.20	1.67	5.50	1.72	1.98	0.530	0.91
101	96.1	2.16	0.680	0.369	0.270	7.76	1.47	5.24	1.09	2.14	0.746	1.13
102	97.6	0.70	0.325	0.852	0.349	7.26	1.03	3.70	0.882	2.37	0.663	0.83
103	94.8	1.91	0.894	0.479	0.369	11.0	1.49	7.19	1.54	2.90	0.947	2.55
104	92.6	3.24	1.77	0.672	0.230	9.26	2.33	8.16	2.11	3.32	0.710	1.74
105	93.7	2.55	1.31	0.478	0.546	10.7	1.94	6.48	1.68	3.37	1.02	1.60
106	97.7	1.29	0.374	0.135	0.252	7.59	1.36	4.69	1.14	2.65	0.511	1.14
107	92.6	3.88	1.04	0.218	1.54	26.8	2.56	10.7	2.81	5.79	0.700	1.10
108	89.9	4.07	1.82	0.594	1.32	15.1	2.70	11.4	1.05	4.36	1.22	1.07
109	89.1	3.96	2.04	0.609	1.18	16.5	2.39	12.3	1.84	6.19	1.14	1.90
110	80.4	8.52	2.54	1.69	1.09	21.8	3.15	24.8	2.35	9.11	1.98	10.6
111	93.3	3.30	1.16	0.636	0.427	9.99	2.35	10.1	1.16	3.51	0.796	1.48
112	97.2	1.50	0.385	0.193	0.287	4.82	1.72	9.54	1.12	2.30	0.570	0.32

APPENDIX B cont.

Station no. UM-SCHEM-73	Molybdenum ($x10^{-4}$)	Nickel ($x10^{-4}$)	Total phosphorus ($x10^{-2}$)	Strontium ($x10^{-3}$)	Zinc ($x10^{-3}$)	Total carbon	Inorganic carbon	Organic carbon	Eh, mv	pH	Depth, m
78	2.48	14.4	2.47	2.90	6.50	2.14	1.35	0.79	60	7.17	13.1
79	0.72	6.92	2.08	2.33	2.84	1.06	0.69	0.37	371	7.88	14.0
80	1.57	6.24	0.0892	1.18	2.48	0.35	0.09	0.26	---	----	15.8
81	1.56	6.38	1.88	1.81	3.41	0.52	0.84	0.0	377	7.70	16.4
82	1.57	11.0	1.78	2.44	3.12	0.89	0.40	0.49	---	----	6.4
83	0.71	5.46	1.44	1.99	2.17	0.96	0.83	0.13	383	7.81	8.2
84	2.46	8.26	2.14	2.76	3.56	1.52	1.21	0.31	440	7.69	11.9
85	5.13	8.94	2.23	2.51	3.92	1.51	1.19	0.32	230	7.87	14.6
86	2.88	8.43	2.60	2.33	3.67	1.58	1.28	0.30	420	7.57	16.8
86B	16.0	17.6	3.41	2.94	7.87	2.62	1.95	0.67	45	7.42	16.8
87	1.03	3.19	0.574	0.795	2.51	0.20	0.13	0.07	150	7.76	16.8
88	5.50	11.9	2.95	2.49	5.37	2.16	1.83	0.33	107	7.39	18.0
89	0.28	2.42	0.544	0.513	1.92	0.27	0.14	0.13	410	7.42	19.2
94	1.24	4.38	1.16	1.63	1.66	0.85	0.39	0.46	413	7.87	4.9
94A	1.57	5.96	1.13	1.74	3.68	0.73	0.47	0.26	---	----	4.9
95	1.62	5.29	1.13	1.70	3.60	0.95	1.01	0.0	361	7.86	7.9
96	9.59	12.2	2.47	2.86	4.98	2.20	1.89	0.31	80	7.46	12.2
97	2.74	6.71	1.69	1.70	2.96	1.27	1.14	0.13	354	7.85	14.3
98	1.31	5.00	0.981	1.35	2.07	1.05	0.80	0.25	405	7.89	7.3
99	1.51	3.99	0.748	1.22	2.29	0.72	0.60	0.12	480	7.76	11.3
100	0.91	3.13	0.577	0.811	1.88	0.48	0.39	0.09	461	7.89	13.4
101	1.13	3.56	0.821	0.812	2.46	0.82	0.55	0.27	403	7.68	16.4
102	0.83	3.32	0.725	0.610	2.01	0.24	0.03	0.21	479	7.62	18.0
103	2.55	5.21	0.892	0.929	3.73	0.92	0.72	0.20	419	7.42	19.8
104	1.74	5.54	0.914	1.52	2.65	1.05	0.86	0.19	320	7.64	7.6
105	1.60	4.17	1.06	1.28	2.27	0.97	0.68	0.29	369	7.69	11.9
106	1.14	3.46	0.635	0.661	1.73	0.19	0.04	0.15	398	8.11	12.8
107	1.10	7.07	2.41	1.40	2.23	0.78	0.37	0.41	---	----	6.7
108	1.07	6.59	1.50	1.98	2.86	1.00	0.92	0.08	456	7.83	8.2
109	1.90	10.2	1.63	2.29	3.17	0.52	0.40	0.12	446	7.47	12.2
110	10.6	13.9	2.84	2.77	6.07	2.31	1.80	0.51	87	7.66	16.2
111	1.48	5.38	1.07	1.35	3.55	1.17	0.54	0.63	379	7.73	18.3
112	0.32	2.99	0.535	1.06	2.42	0.58	0.58	0.0	439	7.67	19.5

APPENDIX C. Limit of detection for elements analyzed by atomic absorption spectrophotometry. These limits apply only to the data presented in this publication.

Element	Limit (weight percent)
Ca	2.1×10^{-3}
Mg	2.5×10^{-2}
Fe	9.1×10^{-4}
Mn	8.9×10^{-5}
Na	1.3×10^{-4}
K	1.2×10^{-3}
Ba	1.6×10^{-4}
Co	1.2×10^{-5}
Cr	4.4×10^{-5}
Cu	1.2×10^{-5}
Mo	6.2×10^{-5}
Ni	8.3×10^{-5}
P	5.0×10^{-3}
Sr	4.2×10^{-5}
Zn	9.6×10^{-5}